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The program in inverse problems included three months of concentration on inverse scattering and spectral problems, ocean acoustic, exploration geophysics, medical imaging and computerized tomography, and non-destructive evaluation. There were two tutorials. The first one was on inverse problems in electromagnetic wave propagation and the second one was on inverse problems in acoustic wave propagation. This was followed by two weeks workshop organized by Bill Symes, G. Papanicolaou, Paul Sacks, K.T. Smith, Guy Chavent and Jan Achenback. The workshop brought together approximately 120 researchers from both university and industry, working on different aspects of inverse problems, and we expect that many new research contacts were initiated during this period.

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INVERSE PROBLEMS IN WAVE PROPAGATION

FINAL REPORT

Period Covered by This Report: 11/1/94–9/30/95

AVNER FRIEDMAN

November 30, 1995

OFFICE OF NAVAL RESEARCH

Grant N00014–95–1–0291

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I. Brief Summary:

The program in inverse problems included three months of concentration on inverse scattering and spectral problems, ocean acoustic, exploration geophysics, medical imaging and computerized tomography, and non-destructive evaluation. There were two tutorials. The first one was on inverse problems in electromagnetic wave propagation and the second one was on inverse problems in acoustic wave propagation. This was followed by two weeks workshop organized by Bill Symes, G. Papanicolaou, Paul Sacks, K.T. Smith, Guy Chavent and Jan Achenback. The workshop brought together approximately 120 researchers from both university and industry, working on different aspects of inverse problems, and we expect that many new research contacts were initiated during this period.

II. Evaluation by the workshop organizers and other IMA Visitors:

William Symes

I was very pleased to learn that ONR is funding the March workshop, and of course would like to help that connection stay healthy. I am on the road at the moment and only just yesterday got my email straightened out. So I hope this is not too late to be useful.

Overall, I think that the subject is due for a large infusion of insight from science and engineering applications. There are certainly interesting mathematical developments underway, for example the large current interest in so called downward continuation methods for elliptic problems (Cheney and Sylvester spoke about this), exploration of bounded variation constraints (Acar and Vogel, Santosa and Dobson), better understanding of nonlinear regularization (Engl, Neubauer, and the Austrian school, unfortunately not represented at the workshop), and vastly improved theory of direct and inverse problems for 1D waves in very heterogeneous media (Papanicolaou and collaborators). However, in my opinion the most interesting work for the next while will be very close to applications.

I will mention a couple of areas that seem to me ripe for progress in the near future. Obviously, my own interests will color my choices, but, I think not too much.

Theoretical reflection seismology has benefitted greatly from the "scale - separated" viewpoint, which partly linearized the dependence of the wavefield on the coefficients of the wave equation. Short scale coefficient components are treated as first order perturbations about smooth background fields. The latter (notably wave velocities) still have nonlinear influence. One could say that this approximation is entirely responsible for the existence of reflection seismology as a discipline, and it's not yet tapped out. Over the next couple of years however, I expect the theory of this approximation will finally approach completion. Beylkin, Burridge, and Rakesh supplied the proper theoretical venue (microlocal analysis) in the 1980's, and treated the local version of this description of scattering. Recently, Smit and his coworkers, Uhlmann, and Nolan and myself, have come close to completing the global picture, with a complete account of scattering in the vicinity of caustics. Chavent, Gerard Herman, and my group have made considerable progress in devising algorithms to estimate the smooth background parameters as well. Most of this work so far has concerned the simplest models, but in the next few years all of this will be extended to quite realistic models of seismic wave propagation in the upper crust and radar wave propagation in the near surface, with attenuation and anisotropy properly accounted for (deHoop, Smit, and Burridge have laid the groundwork for proper treatment of anisotropy). Chavent has made some progress in developing a sound theoretical basis for scale separation, but more work is needed.

I wish to emphasize the nature of this work. It is quite rigorous, relying extensively on modern analysis of PDEs. On the other hand its intellectual context is very much that of the application, in this case exploration geophysics. It is oriented toward computation, and will be applied to field situations with little delay.

Two very different talks at the workshop represented another trend which I believe will be elaborated extensively in the next few years: analysis of information content of data. Stark's work on reliability of whole earth tomography, and Foster and key's presentation of the "mudrock line" interpretation of amplitude-versus-offset analysis of reflection seismograms, both show how careful analysis can distinguish information from artifact in linear inverse problems. I expect this type of analysis to become more useable, with better displays of its conclusions to enhance interpretation, and more refined, accounting for nonlinearity. Every applied inverse problem will benefit from these developments, with ocean acoustics, medical imaging, and nondestructive evaluation particularly ripe.

Papanicolaou and his associates have developed a very extensive theory of bulk behaviour of plane waves in finely laminated materials, with considerable predictive capacity. Most Earth materials, for example, are highly disordered but not laminated, or only approximately laminated. The bulk behaviour of waves in nonlaminated materials, for instance apparent attenuation and dispersion of pulses due to scattering, is qualitatively different from that in laminated materials, due to absence of resonances. Progress in understanding these phenomena is very important, for example in permitting the theory of reflected wave inversion to move beyond linearization based on scale separation. The development of magnetic resonance imaging of rocks and thin section digitization, and of microscopic porous fluid dynamics techniques, should permit both computational and laboratory tests of bulk wave theory in the next few years.

So these are my "picks." You would be entirely within your rights to wave them in my face in five years.

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George Papanicolaou

First, I would like to point out that the March 6–17, 1995 IMA Workshops on 'Inverse Problems in Wave Propagation' was enormously successful and, in my view, the best part of our program on 'Waves and Scattering' for the 1994–95 year at IMA. I feel free to say this as Chairman of the organizing committee for the program because the winter period on 'Inverse Problems', and the March workshop in particular, were conceived and organized by Bill Symes almost entirely. The rest of the committee was happy to go along with his ideas and proposals. The program was truly interdisciplinary, original and exciting both for the mathematics and its applications.

The most pressing issue in Inverse Problems in Wave Propagation is to bridge the gap between theoretical studies of inverse problems and the mostly empirical methods that are used in imaging. To paraphrase Jon Claerbout, it was an eye opening experience for him back in the late sixties and early seventies to move from the study of inverse problems in seismology as they came up in the nuclear treaty verification context to the world of seismic imaging as was (and still is) practiced by the hydrocarbon exploration industry. Seismic imaging deals with the underlying inverse problem in a very naive and oversimplified way but is very sophisticated in the way it deals with the available data (time traces of amplitude at different offsets, different source locations, etc.). Relatively simple amplitude versus offset analysis and transformation of the data gives a crude but frequently quite adequate picture of the structure of the velocity as a function of position down to depths of a five kilometers or so. The best mathematical studies to date (Bleistein's group at the Colorado School of Mines and Symes' group at Rice) do not really explain why this simple minded analysis works as well as it does and, more important, how the theory can point the direction for improvements. But their efforts and their work are taken very seriously in the seismic exploration community and this is a major achievement for theoreticians. Other theoreticians working successfully in this area are Burridge, deHoop, Beylkin and Cheney.

To finish Claerbout's remarks I should also point out that in nonproliferation seismology the theoreticians did succeed in getting accurate yields by the mid-eighties, but they did it in an entirely empirical way. Contrary to what is happening in exploration seismology, there are almost no theoreticians now working on getting a good basic understanding of why the empirical theory works (and how to improve it!). There are lots of really interesting theoretical problems there that have to do with mode coupling of elastic waves by inhomogeneities over long distances near the surface. The role of radiative transport theory in seismology is not well understood today, despite the fact that it has been used for more than

ten years now (by Wu, Sato, Aki and others). But as in exploration seismology most researchers are, at present, heavily involved with the management (data compression, archiving protocols) of very large data sets.

I should mention that velocity estimation in seismic exploration, a basic statistical problem, has received very little attention from first principles except in my own work with Kohler, White, Burridge and others. Despite the fact that we have solved and implemented almost completely several idealized but quite relevant direct and inverse seismic problems that are dominated by noise effects (as is the case in the real world), we have not succeeded in turning our ideas and results into useful tools for the exploration seismologists. There is gap both in applicability and in complexity between what we do and what the exploration people are prepared to do (with their much larger data sets, etc). A lot more must be done in understanding the role of noise in seismic data. It does increase the complexity of the mathematical problems but it also provides a natural mechanism for stabilizing some inherently unstable inversion processes.

Seismic applications are by far the biggest clients of research in 'Inverse Problems in Wave Propagation'. However, in the last ten to fifteen years, ocean acoustic tomography has developed rapidly and has posed several versions of inverse problems that are interesting and subtle. Much of the field work is based on travel-time tomography with a least-squares inversion. In my view, the most interesting theoretical ideas here are in the work of Berryman and his collaborators who have used the variational structure of travel times (Fermat's principle) to get a-priori feasibility bounds for the inversion results. This has the very desirable effect of making least-squares inversion much more stable and more rapidly converging. Berryman's work is not as well known as it should be, I believe, both by theoreticians and practitioners. When noise effects are added from first principles we have some very exciting mathematical problems coming up that need detailed study.

Margaret Cheney

Spending my sabbatical at the IMA, for its special year on waves and scattering, was very constructive for me. I learned a great deal by attending most of the talks at most of the tutorials and workshops. I had many useful conversations with visitors to the IMA. I worked on the following problems:

Finishing the Layer-Stripping Paper.

I finished up my paper with David Isaacson on a layer-stripping approach to reconstructing a perturbed dissipative half-space. This paper appeared in the IMA preprint series, and was published in Inverse Problems. While at the IMA, I gave a number of talks about this work.

Consulting for Endocardial Solutions

The presence of both myself and Eric Voth at the IMA led me to a formal consulting arrangement with Endocardial Solutions, a small start-up company. This company is attempting to develop an electrical system for treating cardiac arrhythmias without open-heart surgery. They do this by passing into the heart a probe covered with electrodes. The success of the system depends on using the probe to sense the location of conduction abnormalities. This involves the following three main mathematical problems 1) Given voltage measurements on the probe due to current sources on the probe, determine the location of the endocardium; 2) Given the location of the endocardium, map the naturally occurring electrical potentials on the endocardium; 3) Use the probe to determine the location of an additional ablation catheter.

These problems are all ill-posed inverse problems reminiscent of the electrical impedance imaging problem I work on at Rensselaer.

Modelling an Anesthesia Breathing System.

I worked with Paul Bigeleisen, a staff anesthesiologist at St. Paul-Ramsey Medical Center, in developing a mathematical model of the breathing system used to administer anesthesia. This problem is very much in the spirit of the IMA Industrial Mathematics program, in that it involved: 1) a practical, real-world problem, 2) close collaboration between physician and mathematician, 3) modelling work, and 4) experiments.

The problem is described in the following excerpt from the introduction to our paper.

A critical time in the administration of anesthesia is the period called induction when the patient has received a drug dose sufficient to paralyze the muscles of respiration, but before tracheal intubation and mechanical ventilation has commenced. So that the anesthetist will have the most possible time to accomplish intubation before the patient become hypoxic, the patient should start with the greatest possible oxygen reservoir. In particular, the nitrogen normally in the lungs should be replaced with oxygen before induction. This process, called denitrogenation, is accomplished a few minutes before the anesthetic drugs are given by having the patient breathe pure oxygen through a mask connected to the breathing circuit. This circuit is also connected to the anesthesia vapor machine and is used to administer anesthetic gases after induction and intubation. There has been considerable debate within the anesthesia community as to the most efficient method to accomplish denitrogenation. In 1981, Gold, using blood gas samples, showed that four deep breaths from a standard circle system produced an oxygen concentration in the blood equivalent to that accomplished by breathing normally for five minutes from the same circle system. Thereafter, it became standard practice to have the patient take four deep breaths of pure oxygen prior to the induction of anesthesia. More recent studies, using pulse oxymetry and in line mass spectrometry, have suggested that four deep breathes are not as efficient at denitrogenation as normal tidal breathing for three minutes. The latter authors suggest, without evidence, that greater rebreathing of nitrogen from the circle system when large breaths are taken, is the cause for inefficient denitrogenation. With rebreathing, the patient is actually recycling part of his/her own breath, including nitrogen, through the circle system. This effect slows down the elimination of nitrogen from the lungs.

In order to determine the most efficient method of denitrogenation, we developed a model of the circle system and compared it to experimental data using the authors as subjects.

Our mathematical model consisted of a system of 8 coupled differential-delay equations. We implemented this model in Matlab. We have nearly completed a paper based on this work.

Processing of Radar Data

I discussed with a number of visitors my ideas for using a geometrical optics expansion to recover the surface electrical properties of a material from the first reflection of a radar pulse. Greg Beylkin suggested that a certain matrix in my scheme might be ill-conditioned, which led me to a method for overcoming this difficulty. Ingrid Daubechies gave me some advice on windowing techniques for signal processing.

Wave Propagation in Random Media

While listening to talks on wave propagation in random media, I started wondering if the method of multiple scales could be used to study the propagation of electromagnetic waves in sea ice. This is a difficult wave propagation problem, because sea ice contains a multitude of pockets of brine and air, which are strong scatterers of electromagnetic waves. I discussed this problem with a variety of visitors, who uniformly found the problem very intersting but did not know how to solve it. I am continuing to think about this problem back here at RPI, and am discussing it with Julian Cole.

Other Connections with Industry

Doug Huntley

One of the industrial postdocs, arranged for me to give a talk at 3M. This eventually led to an arrangement between 3M and my impedance imaging research group at Rensselaier, in which 3M supplies us with electrodes. I discussed with keith Kastella, a staff scientist Unisys, the possibilities for using electrical impedance imaging to determine the extent of ground contamination at waste disposal sites. Our discussions led to an improvement in the algorithm he was developing. I met with representatives of Renaissance Technologies to discuss similarities between the Rensselaer impedance imaging device and their IQ system for assessing cardiac function. The IQ system uses the bulk electrical resistance of the torso, together with sophisticated signal processing techniques, to recover information about cardiac function.

Tuncay Aktosun

of the Mathematics Department of North Dakota State University visited the IMA during January 1-March 31, 1995. He interacted with many scientists visiting the IMA and benefited very much from his visit.

Dr. Aktosun's recent work involves the scattering and inverse scattering problems associated with quantum mechanics and wave propagation. In particular, he works on the Schroedinger equation and the wave equation with variable speed. The inverse scattering problem consists of obtaining a coefficient in these equations in terms of an appropriate set of scattering data. It is possible to combine these two equations to get a generalized Schroedinger equation: for the special choice of the coefficients this generalized equation reduces to the Schroedinger equation and to the frequency-domain version of the wave equation with variable speed, respectively. The generalized equation itself governs the wave propagation in a nonhomogeneous medium when there is a restoring force present in the medium.

While at the IMA Dr. Aktosun worked on both one dimensional and three dimensional versions of these equations. The wavefield of the frequency-domain wave equation can be obtained by solving a Riemann-Hilbert problem; however, the solution of the latter problem requires that one knows the large (complex) frequency asymptotics of the wavefield. In three dimensions these asymptotics are not yet known and the knowledge of these asymptotics will be a giant step in the recovery of the wavespeed in a nonhomogeneous, nonspherically symmetric medium. Dr. Aktosun learned from Michael E. Taylor at the IMA that, under certain restrictions, the large (real) frequency asymptotics of the wavefield grow no faster than the 3/2 power of the frequency. Currently, he is working on the generalization of this result to complex frequencies.

In a one-dimensional medium where the properties change abruptly at a finite number of interfaces, while at the IMA, Dr. Aktosun developed an exact procedure to obtain the discontinuities from the large frequency asymptotics of a reflection coefficient. The results obtained are used in a method currently being developed to obtain the full wavespeed from the reflection coefficient.

Dr. Aktosun interacted with Paul Sacks regarding the recovery of the potential of the Schroedinger equation when the phase of the reflection coefficient is unknown. He communicates with Dr. Sacks on this and various other problems of mutual interest; Dr. Sacks was also visiting the IMA during January-March, 1995.

The Preprints:

[1] T. Aktosun, M. Klaus, and C. van der Mee, Recovery of discontinuities in a nonhomogeneous medium, IMA May, 1995, preprint #1310.

[2] T. Aktosun, Inverse Schroedinger scattering on the line with partial knowledge of the potential, IMA August, 1995 preprint.

[3] T. Aktosun and C. van der Mee, partition of the potential of the one-dimensional Schroedinger equation, IMA August, 1995 preprint.

Paul Sacks

While visiting the IMA, January–March, 1995

1) In joint work with Rakesh (University of Delaware) we have proved a global uniqueness theorem for a one dimensional inverse problem for the variable impedance wave equation, in which finite time transmission data is the given information. This work also presents a numerical solution method.

2) Joint work with J. McLaughlin (R.P.I.) was continued, on the subject of inverse problems for acoustic media involving interior transmission eigenvalues. This kind of problem arises as a special case of the more general and well-known problem of determining the sound speed distribution in $\mathbb{R}^3$ from knowledge of far-field patterns. Our work is mainly concerned with uniqueness and non-uniqueness theorems, and also with the development of numerical methods.

3) The opportunity to meet with V. Yakhno (Siberian Academy of Sciences, Novosibirsk, Russia) has led to the formulation of plans for more long term collaboration on certain inverse problems in linear elasticity.

General Remarks about Contributions of the IMA Visitors:

1) The tutorial lecturers gave a great many interesting and enlightening talks. They were very well appreciated by the IMA audience in residence at the time.

2) The main workshop in March brought together researchers from many different scientific and engineering disciplines who ordinarily would have little contact with each other. For the mathematicians attending the conference it was a fairly unique opportunity to learn about and discuss some very practical and important inverse problems arising in a number of scientific areas.

Michael Taylor

Here's a report on some IMA activities I'm aware of. I hope it will be useful.

In the workshop on inverse problems, the connection between stabilization of various ill-posed problems and the Carleman estimates arising in unique continuation theorems was brought out clearly, particularly by V. Isakov. A month later, C. Bardos brought out similar connections between unique continuation and control theory. Both made use of recent results of D. Tataru.

A different sort of microlocal attack on stabilization of a class of inverse boundary problems was made by M. Taylor, in work completed at the IMA. The work chiefly dealt with linearized inverse problems. Conversations between Taylor and W. Symes have suggested directions for further progress on the nonlinear problem. Work here is still in progress.

C. Liu reported on progress on inverse problems for scattering of waves by Lipschitz obstacles, joint work with A. Nachman. One consequence of this work bore on the famous problem of uniqueness of a obstacle given scattering data at one frequency, and one incident direction. they showed that, at most, finitely many Lipschitz obstacles can have such common data. One offshoot arose in conversations between Liu and M. Taylor: one can identify a sphere in IR^3, given scattering data at one frequency, from any two linearly independent incident directions.

Work on Lipschitz boundaries connected with other work, both at the IMA and in the mathematics department at Minnesota, particularly works of E. Fabes and of M. Mitrea. The latter, in joint work with J. Pipher, examined direct scattering problems of electromagnetic waves by Lipschitz boundaries. This work had further contact with work of M. Taylor, on the Euler and Navier-Stokes equations for incompressible fluids. Work on this is still in progress; one direction involves a possible simplification and further extension of recent work of P. Deuring and W. von Wahl, on the Navier-Stokes equations in a Lipschitz domain. Taylor reported on progress on the Euler equations in the department's PDE seminar.

M. Cheney presented work on layer stripping as a technique in inverse problems. This involves examination of the Dirichlet-to-Neumann map. In conversations with M. Taylor it was seen that this technique has interesting similarities with analysis brought to bear on the $\overline{\partial}$-Neumann problem.

In the workshop on singularities and oscillations, there was particular interest in the behavior of solutions to semilinear wave equations. J. Rauch described some models for the propagation of electromagnetic waves, interacting with a semiconducting medium, which might better accommodate observed phenomena of dispersion than standard models. Several participants, including H. Lindblad and Tahyildar-Zadeh, have been studying semilinear wave equations whose nonlinear terms satisfy a 'null condition.' One significant example is the wave map equation, a Lorentz analogue of the harmonic map equation, of interest to physicists because of its role in 'nonlinear σ-models.' Wave map equations belong to a class for which classical solutions can blow up in finite time. S. Alinhac spoke on a general study of mechanisms for blow-up of solutions, a subject on which S. Kichenassamy has also been active.

An interesting study of some quasilinear systems was made by R. Rosales. He gave a talk on the difference between long-time behavior of solutions to the 2×2 and the 3×3 systems of compressible fluid dynamics, in one space variable, including newly discovered families of persisting waves for the 3×3 system.

In the workshop on quasiclassical methods, connections with quantum statistical mechanics were noteworthy, and played an important role in the tutorial of B. Helffer. The message is that 'classical' manifestations of physical phenomena, obeying underlying laws of quantum mechanics, arise not only because one is looking on a dimensional scale in which Planck's constant is small, but also because one is looking at the interaction of a large number of particles. An IMA visitor, V. Jaksic, was working on the interaction of particles with a 'heat bath,' both classical and quantum mechanical, and was pursuing a dynamical theory of Brownian motion using such a model.

David Finch

During the winter of 1995, while a visitor at the IMA, I began again to study a problem which had intrigued me some years ago. In a mathematical model of single photon emission tomography, measurements exterior to a body $\Omega \subset R^2$ with (variable) attenuation coefficient a and distribution of radioactive emitters f can be represented by an integral transform along directed lines L given by

$$R_a f(L) = \int_L f(x)\mu(x,\theta)dx$$

where the integral is taken with respect to arc length, θ is the direction of L as a point in the unit sphere, and $\mu(x,\theta)$ is the exponential of the negative of the integral of a over the ray starting at x with direction θ. Many questions about this generalized Radon transform remain open: two which I have been interested in are uniqueness when a is known and the bolder question, much studied over a period of 10 years by Natterer, of uniqueness of both a and f from full measurement over all lines passing through the support of the unknown functions. For the second question, there is a known class of counterexamples. Namely, if Ω is the unit disk and both a and f are redial functions the $R_a f$ is radial, but it is known that such a function is in the range of the operator R_a for $a = 0$. The project I began at the IMA is to look at the linerization of this question: that is to investigate uniqueness questions about the differential of the map $(a, f) \to R_a f$. Even for the simplest case, when $a = 0$ so that one has the classical x-ray transform, the question of injectivity of the differential leads to non-standard problems in integral geometry, which as yet are unsolved.

Two germs of projects, begun in conversations with other visitors at the IMA, but not much advanced, are the analysis of the classical Radon transform in the space BV, which would seem to better model the kinds of density functions one might see in applications, and the application of some uniqueness theorems of integral geometry to some special inverse problems for the wave equation. There has been much work done on the latter by the Novosibirsk school: the question is to see whether integral geometry can substitute for results in partial differential equations.

Rakesh

During my stay at the IMA from January 7, 1995–April 15, 1995, I worked on two problems

- Inversion from transmission data for the one dimensional wave equation
- Inversion from point source data for a multidimensional inverse problem for the wave equation

The first problem was solved jointly with Paul Sacks and the article based on this has been submitted to *Wave Motion*. Conversations with David Finch led to results on subproblems of the second problem and discussions with Walter Strauss and Daniel Tataru have resulted in ideas on how to tackle the full problem. In addition, I attended the tutorial and the workshop on Nonlinear Waves in April and I think the tutorials of Beals and Taylor will pay dividends in the future. Below, I give a more detailed description of the two problems I studied.

Inversion from transmission data for the one dimensional wave equation

Suppose $\eta(x)$ is a positive function in $W^1\_infty(0,\infty)$ (i.e. one bounded derivative), is constant for $x > X$ for some known positive number X. Consider the initial boundary value problem

$$\begin{aligned} \eta(x)u_t t(x,t) - (\eta(x)u_x(x,t))x &= 0, & 0 \le x, t \in R \\ (u(x,t) &= 0, & 0 \le x, t < 0 \\ u_x(0,t) &= \delta(t), & t \in R \end{aligned}$$

where δ is the usual Dirac delta function. From causality, u is zero for $t < x$. Further, using energy estimates, one may show that the above initial boundary value problem has a unique solution which is locally H^1 in the region $t \ge 0$. We were interested in the inverse problem of recovering η from transmission data $u(X,.) - X$ fixed. We proved

Assume $\log \eta \in W^1\infty(0, 2X)$, and η is constant for $X \leq x \leq 2X$. Then $\frac{\eta(x)}{\eta(0)}$ is uniquely determined by $u(X, t)$, $X \leq t \leq 3X$.

Further, our proof was constructive, and we tested a numerical implementation of our algorithm.

Inversion from Point Source Data for a multidimensional inverse problem for the wave equation

Suppose $q(x)$ is a smooth function on R^3 with q zero outside the a ball of radius ρ. Consider the initial value problem

$$u_{tt} - \Delta_x U + q(x)u = \delta(x, t) \qquad x \in R^3, \qquad t \in R$$
$$u = 0 \qquad \text{for} \qquad t < 0$$

Using standard techniques ones can show that this initial value problem has a unique smooth solution over the region $t > |x|$ - the solution is zero on $t < |x|$. Our goal was to study the inverse problem - given $u(x, t)$ on $\{x : |x| = \rho\} \times [\rho, 3\rho]$, determine q.

I can now show that there is uniqueness for the inverse problem provided we restrict our attention to the class of functions q which have small L^∞ norms. However, I wish to prove a similar result without any restrictions on the size of q. I have some ideas on how to tackle the general problem based on the work of Tataru but this is a long term project.

Valery E. Grikurov

Some Aspects of Soliton Behaviour in a One-Dimensional Nonintegrable Schrödinger Model

The propagation of lasers through nonlinear optic media is described by the nonlinear Schrödinger (NLS) equation

$$\imath\psi_t = \Delta\psi + F(|\psi|^2)\psi, \tag{1}$$

where "time" t is a coordinate along the direction of propagation and Δ is the Laplacian with respect to transverse variables. The most popular version of the equation (1) is the one-dimensional (1D) "cubic" NLS:$F(\xi) = \pm\xi$. The case with the minus sign is called "focusing": the nonlinearity tends to compress a wavetrain. Due to the balance of dispersion and the compression, the soliton, that is, the localized finite energy solution, exists for both the 1D and the multidimensional focusing NLS equation. In the 1D case, the "cubic" NLS equation can be studied by the inverse scattering transform technique. In particular, solitons are known to be *stable* under small perturbations and even *superstable*, that is, they are able to survive in collisions.

The nonlinear potential term in (1) arises due to the optic medium's response to intensive electromagnetic radiation. The "cubic" nonlinearity includes this response only in the first order, and examination of more general nonlinearities is natural. The simplest model which generalized the "cubic" one is the polynomial $F(\imath) = \imath^p + \delta\imath^q$, $\quad q > p, \quad \delta > 0$, which at the same time poses the features of some models of saturation nonlinearity.

We study the following solitonic properties for the equation (1) (only in 1D for the moment): 1) the stability of solitons and 2) their behavior in collisions. It appears that solitons of the non-integrable NLS equation no longer have the stability properties. In particular, one can expect the phenomena of rebuilding of solitons both due to perturbation and collisions. The rebuilding means that at a long time the solution contains soliton(s) whose parameters are *not* close to the parameters of the initial soliton(s). The details may be found in [1].

The example leads to the conjecture which is formulated below. This conjecture is based on numerous computer experiments which were performed during the IMA experience of the author.

Let solitons be parameterized by the single parameter w, and let $N(w)$ denote the L_2-norm of the soliton $u_0(x; w)$. Suppose that $N(w)$ has a minimum at $w = w$. (in other words, the system admits the existence of both unstable and stable solitons). Then for $w < w_*$ there exists some positive λ_* such that the equation (1) has a solution of the form $U_w(e^{\lambda_* t}, x) = \sum_{k=0}^{\infty} e^{k\lambda_* t} u_k(x; w)$, where $u_k(x; w)$ are determined by some recurrent procedure. After a long time, the dominating part of this solution is another soliton with the frequency $w_\infty > w_*$. The conjecture: if $u_{t=0} = u_0(x; w) + v(x)$ where $v(x)$ is small in the appropriate norm, then $u(x, t) = \overline{U_{\tilde{w}}(e^{\lambda * t}; x) + o(1)}$ when $t\infty$, where $\tilde{w}$ is close to w.

References

[1] V.E. Grikurov. Soliton's rebuilding in one-dimensional Schrödinger model with polynomial nonlinearity. IMA Preprint Series # 1320, July, 1995.

Let us consider the following integro-differential equation of hyperbolic type,

$$u_t t - m\left(\int_\Omega |\nabla_x u|^2 dx\right)\Delta_x u = 0, \tag{1}$$

where m is a smooth function satisfying $m(s) \geq v > 0$, for any $s \geq 0$, and Ω is any open subset of $\mathbb{R}^N$. eq. (??) represents a nonlinear model for the vibrations of strings or membranes and in the last fifty years has been the subject of several studies from the pure mathematical point of view. In spite of the apparent simplicity of Eq.(??) and unlike the well-known results on hyperbolic equations of local type, it is not known whether or not regular solutions develop singularity in finite time. In general not very much is known about the qualitative behaviour of solutions of Eq.(??).

During my permanence at the IMA I took advantage of the workshop on "Singularity and Oscillations" to learn the recent developments of Nonlinear Geometric Optics and to begin a collaboration with Prof. Olivier Guès. The aim of this collaboration has been that of investigating the behaviour of oscillating solutions of Eq.(??) in the case when $\Omega \equiv \mathbb{R}^N$. The main result consists in the construction of small amplitude and high-frequency solutions of Eq.(??), i.e. solutions depending on a small parameter ε, of the form

$$\overline{u}(x,t) = \varepsilon^{3/2}\left\{\sum_{j=0}^{M-1} \varepsilon^j V^j(x,t,\varphi(x,t)/\varepsilon) + O(\varepsilon^M)\right\} \qquad (M \geq 1), \tag{2}$$

where the *profiles* $V^j(x,t,\theta), j = 0,\ldots,M-1$, are smooth functions 2π-periodic in θ and the *phase* φ is a solution of the characteristic equation of the linearized operator in zero. The presence of the factor $\varepsilon^{3/2}$ guarantees on one hand the validity of the expansion (??) in a time interval $[0, T(\varepsilon)]$, with $T(\varepsilon) = O(\log(1/\varepsilon))$ and on the other hand that the size of the oscillations is sufficiently large to have a genuine nonlinear perturbation theory. The principal part of the expansion (??) is of particular interest (the so called geometric optics term). In the case of Eq.(??) turns out to be a global (in time) solution of a quasilinear integro-differential transport equation. These results have been recently presented at the congress of the Italian Mathematical Society but the paper is still in preparation.

Solutions of the form (??), depending on a single phase, are called simple wave. Our next goal would be that of studying the Cauchy problem with oscilla ting initial data, where the interaction resonance) of several waves with different phases renders the problems more difficult and interesting.

David Sattinger

I found the past year to be extremely helpful in gaining a better perspective on higher dimensional inverse scattering problems; and on the methodology used in industrial problems. My own area of expertise lies in the area of one-dimensional problems and their application to completely integrable systems. The emphasis of the current year was on multi-dimensional problems, and their applications in seismology and inverse conductivity problems.

Here I will describe briefly some of the lectures that made a particular impression on me and that I found useful.

One-dimensional problems tend to be well–posed mathematical problems, both from the standpoint of unique determination of the unknown functions by the data, and from the viewpoint of stable inversion algorithms, such as the Gel 'fand-Levitan-Marchenko integral equations, or Riemann-Hilbert problems.

The inversion of multi-dimensional problems, by contrast, generally involves highly unstable algorithms. Some of these algorithms were discussed by Margaret Cheney in her lectures. George Papanicolaou even pointed out that the one-dimensional problems, though well–posed from a theoretical point of view, are nevertheless destabilized by the necessity of selecting only part of the data. (It is impractical to obtain the full set of data for a problem; only partial information is available from the field.)

Recent progress has been made in unique determination of the potentials from the data. This began with the work of Adrian Nachman and continued with Slyvester and Uhlmann. That work has been

extended and generalized by Changmei Liu (a student of Nachman's) in her thesis. She reported on her work both in IMA seminars and in PDE seminars in the mathematics department.

Since the full inversion problem is unstable, one must turn to some sort of approximation scheme which aims to recover only rough features of the potentials from singular features of the scattering data. This is the approach being developed by William Symes, who gave a series of lectures on the recovery of singularities of the potentials (such as discontinuities) from the data. Symes' approach is based on the theory of hyperbolic partial differential equations.

Another approach to approximations to inverse problems was discussed in an elegant set of lectures by David Colton of the University of Delaware. Colton discussed the electric far-field operator; this is very nicely developed mathematical theory of the asymptotics of the long range electric field. It gives some information on the scattering object.

Bob Burridge spoke on wave phenomena in nonlinear media and its analysis. In addition, Burridge has developed one-dimensional methods and their application to statefield plane layered geometries. This work displays the interrelationship between certain inverse schemes and explicit finite difference schemes for solving hyperbolic systems, and I have been looking at some of these papers.

The conference in June, organized by Barry Simon, addressed some of the developments in one-dimensional inverse scattering. Fritz Gestezy and Percy Deift both talked on problems in mathematical physics coming from integrable systems. Deift is by now the leading researcher in Riemann-Hilbert problems and their applications to inverse problems in mathematical physics.

Finally, I would like to mention discussions with Postdoctorial fellows Sarah Patch and Shih-Hsien Yu on some of their work.

Patch is working on an interesting kind of inverse problem generated by a kind of Markov process, in which photons enter a box, bounce around randomly, and eventually exit. If one knows the relationship between the entering photons and the exiting photons, one would like to recover the internal transition probabilities. So far, the problem is solved only for the simplest system. The problem displays a number of attributes common to inverse scattering problems: over-determination of data, factorization problems, and so forth. Unfortunately, even at the 2×2 level, the problem is quite difficult, and it remains to be seen whether the full problem will turn out to be tractable.

Shih-Hsien Yu showed me his work the use of weighted norms for finite difference schemes in conjunction with non-linear hyperbolic conservation laws. I had introduced such weighted norms for the study of stability of traveling waves of nonlinear parabolic systems some years ago, and Yu has shown that similar weighted norms can be used to prove the stability of a discrete shock profile. This appears to be a promising direction.

Donald G. Truhlar and Barry Simon

The workshop on Multiparticle Quantum Scattering with Applications to Nuclear, Atomic, and Molecular Physics was held June 12–16, 1995 at the Institute for Mathematics and Its Applications in the University of Minnesota Twin Cities campus as part of the 1994–95 Program on Waves and Scattering. There were about seventy participants including the plenary lecturers whose contributions are included in this volume. The workshop was preceded by a two-day tutorial featuring lectures by Donald J. Kouri and Gian Michele Graf, and we are pleased that Professor Kouri was able to write up his tutorial as the opening chapter of this volume.

Multiparticle scattering theory in quantum mechanics is technically complex because of the variety of scattering channels — for example, if one scatters two hydrogen atoms off each other the possible results include two free protons, two free electrons, or a proton and a hydride ion. A key issue in the mathematical foundations is that of asymptotic completeness which says that any state of the quantum system is a superposition of bound and scattering states.

Asymptotic completeness was proven by Kato and Birman in the late 1950's for two-body systems with short-range potentials and by Faddeev in the early 1980's for three-body problems. Going beyond three bodies turned out to be remarkably hard. There was important progress by Balslev and Combes, Enss,

Mourre, and Perry, Sigal, and Simon, but it was only in 1985 that Sigal and Soffer solved the problem. Their proof is complex, but there has been a significantly simplified extension by Graf and Yafeev.

While mathematicians have been focused inwards on these foundational questions, users of quantum mechanical scattering — notably physicists studying atoms and nucleii and chemists studying atoms and molecules — have been developing computational techniques, and their calculations raise new mathematical issues concerned with the necessity to enforce explicit boundary conditions, the interaction of composite systems with electromagnetic fields, the properties of effective potentials for many-body systems, and the properties of the scattering matrix for resonances.

One of our goals in this workshop was to increase communication between the two sides, to allow the computational side to make contact with the new results of Sigal, Soffer, and Graf and to stimulate the mathematicians by greater contact with users of the theory and the new mathematical issues arising in their work.

The Workshop was a great scientific success, but there were some unfortunate events on the personal side. One of the original co-organizers, W. Hunziker of Zurich, became seriously ill and could not attend. We offer our hopes for his complete recovery. One of our invited speakers, Jens Bang of Copenhagen, broke six ribs the week before the workshop and could not attend. Fortunately, we are able to include his manuscript. Another of our invited participants, Per-Olov Löwdin of Uppsala, was unable to attend due to the death of his colleague Jean-Louis Calais. We offer our condolences to the family and colleagues of Professor Calais.

We would like to express our thanks and those of all the participants to Avner Friedman and Robert Gulliver of the IMA for their help in organizing and hosting the Workshop. It is also a pleasure to thank the IMA staff, especially Joy Paul Schwenke, for their very special assistance in the running of the Workhop and Patricia V. Brick for her usual expert assistance in the production of these proceedings.

III. Manuscripts received for the IMA Volumes in Mathematics and its Applications to be published by Springer-Verlag, New York. The workshops were funded by ONR Grant Number N00014–95–1–0291.

- WAVES IN RANDOM AND OTHER COMPLEX MEDIA (November 14–18, 1994)
  Editors: Robert Burridge, George Papanicolaou and Leonid Pastur

  - Anne Boutet de Monvel and Radu Purice, The conjugate operator method: application to Dirac operators and to stratified media
  - A. Figotin and P. Kuchment, 2D photonic crystals with cubic structure: asymptotic analysis
  - Jean-Pierre Fouque and Josselin Garnier, On waves in random media in the diffusion-approximation regime
  - V. Freilikher, M. Kaveh, M. Pustilnik, I. Yurkevich, J. Sanches-Gil, A. Maradudin, and Jun Q. Lu Coherent Effects in Scattering from, bounded random systems with discrete spectrum
  - Kenneth M. Golden, The interaction of microwaves with sea ice
  - Sergey Gredeskul, Masha Zusman, Yshai Avishai and Mark Azbel, Electron in two-dimensional system with point scatterers and magnetic field
  - Matti Lassas, Inverse spectral problems for random bodies
  - R.C. McPhedran, N.A. Nicorovici, L.C. Botten and Bao Ke-Da Green's function, lattice sums and Rayleigh's identity for a dynamic scattering problem
  - Haruo Sato, Study of Seismogram Envelopes Based on the Energy Transport Theory
  - M.M. Sigalas, C.-T. Chan and C.M. Soukoulis, Propagation of electromagnetic waves in two-dimensional disordered systems
  - Bart A. Van Tiggelen and Roger Maynard, Reciprocity and coherent backscattering of light

- P. K. A. Wai and C. R. Menyuk, Physical models of polarization mode dispersion
- Ru-Shan Wu, Spatio-temporal distribution of seismic power for a random absorptive slab in a half space

- INVERSE PROBLEMS IN WAVE PROPAGATION (March 6-17, 1995)
  Editors: Guy Chavent, George Papanicolaou, Paul Sacks, and William Symes

  - Variational structure of inverse problems in wave propagation and vibration by James G. Berryman
  - Convergence of numerical methods for inverse problems with general input sources by Robert W. Brookes and Kenneth P. Bube
  - Topics in ocean acoustic inverse problems by Michael D. Collins
  - Generalized modes in an acoustic strip by Elisabeth Croc and Yves Dermenjian
  - A survey of selected topics in inverse electromagnetic scattering theory David Colton
  - Inverse scattering problems for Schrödinger operators with magnetic and electric potentials by G. Eskin and J. Ralston
  - Results, old and new, in computed tomography by Adel Faridani
  - Detecting subsurface hydrocarbons with elastic wavefields by D.J. Foster, R.G. Keys and D.P. Schmitt,
  - How many parameters can one solve for in diffuse tomography? by F.A. Grünbaum and S.K. Patch
  - Modeling Scanned Acoustic Imaging of Defects at Solid Interfaces by John G. Harris
  - On reconstruction of the diffusion and of the principal coefficient of a hyperbolic equation by Victor Isakov
  - Directional moments in the acoustic inverse problem by Yaroslav Kurylev and Alexander Starkov
  - Finding the density of a membrane from nodal lines by Ching-ju Ashraf Lee and Joyce R. McLaughlin
  - An Inverse Obstacle Problem: A Uniqueness Theorem for Spheres by Changmei Liu
  - Inverse scattering in acoustic media using interior transmission Eigenvalues by Joyce R. McLaughlin, Paul E. Sacks and Manjula Somasundaram
  - A Layer stripping algorithm in elastic impedance tomography by Gen Nakamura and Gunther Uhlmann
  - Partitioned nonlinear optimization for the interpretation of seismograms by Guust Nolet
  - Applications of inverse methods to the analysis of refraction and wide-angle seismic data by Robert L. Nowack
  - Inversions in astronomy and the SOLA method by Frank P. Pijpers
  - Local reconstruction applied to x-ray microtomography by Erik l. Ritman, John H. Dunsmuir, Adel Faridani, David V. Finch, Kennan T. Smith, and Paul J. Thomas
  - On the layer stripping approach to a 1-D inverse problem by John Sylvester
  - Estimates for approximate solutions to acoustic inverse scattering problems by Michael E. Taylor
  - The r-solution and its applications in linearized waveform inversion for a layered background by V.G. Khajdukov, V.I. Kostin and V.A. Tcheverda
  - A multidimensional inverse problem for lame system and its reducing to the tomography problem by V.G.Yakhno

- SINGULARITIES AND OSCILLATIONS (April 10-14, 1995)
  Editors: Jeffrey Rauch, Michael Taylor
  Organizers: Joseph Keller, Jeffrey Rauch, and Michael Taylor
  - Observation and control of elastic waves by Claude Bardos, Tawfik Masrour, and Frederic Tatout
  - Modeling the dispersion of light by Phillipe Donnat and Jeffrey Rauch
  - Singularities and oscillations in a nonlinear variational wave equation by Robert T. Glassey, John K. Hunter, and Yuxi Zheng
  - Viscous boundary layers and high frequency oscillations by Olivier Gues
  - Non linear oscillations and caustics by J.L. Joly, G. Métivier, and J.Rauch
  - Microlocal analysis on Morrey spaces by Michael E. Taylor
  - Nonlinear Geometric Optics for Reflecting and Glancing Oscillations by Mark Williams
- QUASICLASSICAL METHODS (May 22-26, 1995)
  Editors: Jeffrey Rauch, Barry Simon
  - Approximative theories for Large Coulomb systems by Volker Bach
  - h-pseudodifferential operators and applications: an introduction by Bernard Helffer
  - Semiclassical analysis for the Schrödinger operator with magnetic wells (after R. Montgomery, B.Helffer-A.Mohamed), by Bernard Helffer
  - On the asymptotic distribution of eigenvalues in gaps by Rainer Hempel
  - Asymptotics of the ground state energy of heavy molecules in the strong magnetic field by Victor Ivrii
  - A proof of the strong Scott conjecture—talk at IMA on May 24, 1995 [Draft] by Heinz Siedentop
  - Lieb-Thirring inequalities for the Pauli operator in three dimensions by Alexander V. Sobolev
  - Exact anharmonic quantization condition (in one dimension) by André Voros
- MULTIPARTICLE QUANTUM SCATTERING WITH APPLICATIONS TO NUCLEAR, ATOMIC AND MOLECULAR PHYSICS (June 12-16, 1995)
  Editors: Donald G. Truhlar and Barry Simon
  - The Pauli principle in multi-cluster bound and scattering states by Jens Bang
  - Nonperturbative approaches to atomic and molecular multiphoton (half-collision) processes in intense laser fields by Shih-I Chu
  - Quantization in the continuum - complex dilated expansions of scattering quantities by Nils Elander
  - On trace formulas for Schrödinger-type operators by F. Gesztesy and H. Holden
  - N-body quantum systems: A tutorial by Gian Michele Graf
  - Classical action and quantum N-body asymptotic completeness by Gian Michele Graf and Daniel Schenker
  - A tutorial on computational approaches to quantum scattering by Donald J. Kouri and David K. Hoffman
  - Time-independent wavepacket quantum mechanics by Donald J. Kouri, Youkong Huang, and David K. Hoffman
  - Multiparticle quantum systems in constant magnetic fields by I. Łaba

- Microscopic atomic and nuclear mean fields by C. Mahaux
- Global recursion polynomial expansions of the Green's function and time evolution operator with absorbing boundary conditions by Vladimir A. Mandelshtam
- State-to-state transition probabilities and control of laser induced dynamical processes by the (t, t' Method by Nimrod Moiseyev
- New channels of scattering for two- and three-body quantum systems with long-range potentials by D. Yafaev

IV. Manuscripts published in the IMA Preprint Series from November 1994 to November 30, 1995.

1270 **S. Kichenassamy & G.K. Srinivasan**, The structure of WTC expansions and applications

1271 **A. Zinger**, Positiveness of Wigner quasi-probability density and characterization of Gaussian distribution

1272 **V. Malkin & G. Papanicolaou**, On self-focusing of short laser pulses

1273 **J.N. Kutz & W.L. Kath**, Stability of pulses in nonlinear optical fibers using phase-sensitive amplifiers

1274 **S.K. Patch**, Recursive recovery of a family of Markov transition probabilities from boundary value data

1275 **C. Liu**, The completeness of plane waves

1276 **Z. Chen & R.E. Ewing**, Stability and convergence of a finite element method for reactive transport in ground water

1277 **Z. Chen & Do Y. Kwak**, The analysis of multigrid algorithms for nonconforming and mixed methods for second order elliptic problems

1278 **Z. Chen**, Expanded mixed finite element methods for quasilinear second order elliptic problems II

1279 **M.A. Horn & W. Littman**, Boundary control of a Schrödinger equation with nonconstant principal part

1280 **R.E. Ewing, Yu.A. Kuznetsov, R.D. Lazarov & S. Maliassov**, Substructuring preconditioning for finite element approximations of second order elliptic problems. I. Nonconforming linear elements for the Poisson equation in a parallelepiped

1281 **S. Maliassov**, Substructuring preconditioning for finite element approximations of second order elliptic problems. II. Mixed method for an elliptic operator with scalar tensor

1282 **V. Jakšić & C.-A. Pillet**, On model for quantum friction II. Fermi's golden rule and dynamics at positive temperatures

1283 **V. M. Malkin**, Kolmogorov and nonstationary spectra of optical turbulence

1284 **E.G. Kalnins, V.B. Kuznetsov & W. Miller, Jr.**, Separation of variables and the XXZ Gaudin magnet

1285 **E.G. Kalnins & W. Miller, Jr.**, A note on tensor products of q-algebra representations and orthogonal polynomials

1286 **E.G. Kalnins & W. Miller, Jr.**, q-algebra representations of the Euclidean, pseudo-Euclidean and oscillator algebras, and their tensor products

1287 **L.A. Pastur**, Spectral and probabilistic aspects of matrix models

1288 **K. Kastella**, Discrimination gain to optimize detection and classification

1289 **L.A. Peletier & W.C. Troy**, Spatial patterns described by the Extended Fisher-Kolmogorov (EFK) equation: Periodic solutions

1290 **A. Friedman & Y. Liu**, Propagation of cracks in elastic media

1291 **A. Friedman & C. Huang**, Averaged motion of charged particles in a curved strip

1292 **G. R. Sell**, Global attractors for the 3D Navier-Stokes equations

1293 **C. Liu**, A uniqueness result for a general class of inverse problems

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1299 **E. Casas**, Pontryagin's principle for state-constrained boundary control problems of semilinear parabolic equations

1300 **G.R. Sell**, References on dynamical systems

1301 **J. Zhang**, Swelling and dissolution of polymer: A free boundary problem

1302 **J. Zhang**, A nonlinear nonlocal multi-dimensional conservation law

1303 **M.E. Taylor**, Estimates for approximate solutions to acoustic inverse scattering problems

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1307 **A. Boutet de Monvel & V. Georgescu**, Boundary values of the resolvent of a self-adjoint operator: Higher order estimates

1308 **S.K. Patch**, Diffuse tomography modulo Gramann and Laplace

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1310 **T. Aktosun, M. Klaus & C. van der Mee**, Recovery of discontinuities in a nonhomogeneous medium

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1314 **B. Engquist & E. Luo**, Convergence of a multigrid method for elliptic equations with highly oscillatory coefficients

1315 **L. Pastur & M. Shcherbina**, Universality of the local eigenvalue statistics for a class of unitary invariant random matrix ensembles

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1317 **J. Nečas, M. Ružička & V. Šverák**, On self-similar solutions of the Navier-Stokes equations

1318 **S. Stojanovic**, Remarks on $W^{2,p}$-solutions of bilateral obstacle problems

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1320 **V.E. Grikurov**, Soliton's rebuilding in one-dimensional Schrödinger model with polynomial nonlinearity

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1331 **T. Aktosun & C. van der Mee**, Partition of the potential of the one-dimensional Schrödinger equation

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1344 **G. Avalos**, The exponential stability of a coupled hyperbolic/parabolic system arising in structural acoustics

1345 **G. Avalos & I. Lasiecka**, A differential Riccati equation for the active control of a problem in structural acoustics

1346 **G. Avalos**, Well-posedness for a coupled hyperbolic/parabolic system seen in structural acoustics

1347 **G. Avalos & I. Lasiecka**, The strong stability of a semigroup arising from a coupled hyperbolic/parabolic system

1348 **A.V. Fursikov**, Certain optimal control problems for Navier-Stokes system with distributed control function

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1350 **F. Gesztesy & H. Holden**, On trace formulas for Schrödinger-type operators

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1352 **X. Chen**, Lorenz equations, Part I: Existence and nonexistence of homoclinic orbits

1353 **X. Chen**, Lorenz equations Part II: "Randomly" rotated homoclinic orbits and chaotic trajectories

1354 **X. Chen**, Lorenz equations, Part III: Existence of hyperbolic sets

1355 **R. Abeyaratne, C. Chu & R.D. James**, Kinetics of materials with wiggly energies: Theory and application to the evolution of twinning microstructures in a Cu-Al-Ni shape memory alloy

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1357 **G. Avalos & I. Lasiecka**, Exponential stability of a thermoelastic system without mechanical dissipation

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1366 **K. Bhattacharya & R.V. Kohn**, Elastic energy minimization and the recoverable strains of polycrystalline shape-memory materials

1367 **G.A. Chechkin**, Operator pencil and homogenization in the problem of vibration of fluid in a vessel with a fine net on the surface

1368 **M. Carme Calderer & B. Mukherjee**, On Poiseuille flow of liquid crystals

1369 **M.A. Pinsky & M.E. Taylor**, Pointwise Fourier inversion: A wave equation approach

1370 **D. Brandon & R.C. Rogers**, Order parameter models of elastic bars and precursor oscillations

1371 **H.A. Levine & B.D. Sleeman**, A system of reaction diffusion equations arising in the theory of reinforced random walks

1372 **B. Cockburn & P.-A. Gremaud**, A priori error estimates for numerical methods for scalar conservation laws. Part II: Flux-splitting monotone schemes on irregular Cartesian grids

VI. IMA Newsletter Numbers 221–228

INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

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IMA NEWSLETTER # 221

October 31 - November 26, 1994

1994-95 Program
WAVES AND SCATTERING

See the Fall 1994 IMA Update for a full description of the 1994 - 95 program on Waves and Scattering

News and Notes

IMA Tutorial:
Waves in Random and Other Complex Media
November 9 - 10, 1994
Speakers: Leonid Pastur and Benjamin White

IMA Workshop:
Waves in Random and Other Complex Media
November 14 - 18, 1994
Organizers: Robert Burridge, George Papanicolaou and Leonid Pastur

Board of Governors chooses Future Programs

At its meeting October 9, 1994 in Minneapolis, the Board of Governors of the IMA approved a proposal to select **EMERGING APPLICATIONS OF DYNAMICAL SYSTEMS** as the topic for the academic year 1997 - 1998. The proposal was prepared by John Guckenheimer (Chairman)(Cornell University), Eusebius Doedel (Concordia University), Yannis Kevrekidis (Princeton University), John Rinzel (NIH), and Martin Golubitsky (Univ. of Houston).

The Board of Governors also approved a two-week Summer program for July, 1996 on **EMERGING APPLICATIONS OF NUMBER THEORY.** The organizing committee consists of Dennis Hejhal (Univ. of Minnesota/Uppsala), Joel Friedman (Univ. of British Columbia), Martin Gutzwiller (IBM Yorktown Heights), and Andrew Odlyzko (AT&T Bell Labs).

Future programs approved at previous meetings include LARGE-SCALE OPTIMIZATION, July 10 - 28, 1995; MATHEMATICAL METHODS IN MATERIALS SCIENCE, 1995 - 96; and MATHEMATICS IN HIGH PERFORMANCE COMPUTING, 1996 - 97.

Schedule for October 31 - November 26, 1994

Monday, October 31

SEMINAR IN { **Mathematical Physics** / **Room VinH 570** }

3:30 pm	**Rafael Heredero**	Classification of Integrable Evolution Equations

Abstract: The classification of integrable evolution equations $u_t = F(t, x, u, u_1, \ldots, u_n)$ is discussed, under the (formal) symmetry point of view. A new representation of evolution equations, in the so called non-standard variables, turns out to be surprisingly useful. The proliferation of integrable equations is explained using symmetry concepts and differential substitutions. Finally, the present state of the third order $n = 3$ case is sketched.

Organizer: Peter Olver

Tuesday, November 1

IMA Postdoc Seminar

2:30 pm	**Erding Luo** IMA	Multigrid Methods For Highly Oscillatory Elliptic Equations

Organizer: Erding Luo

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

SEMINAR IN { **Combinatorics** / **Vincent Hall 570** }

4:30 pm	**Jennifer Galovich** St. John's University	To be announced

Victor Reiner, Organizer

Wednesday, November 2

Thursday, November 3

IMA Industrial Postdocs Seminar

The seminar will meet from 1:00 pm - 4:00 pm today. The format of the seminar is:

1. Presentation of projects and problems from industry (Honeywell, Siemens, 3M and Unisys) on which the industrial postdocs are working.
2. Informal suggestions and discussion among the participants.

The seminar is directed by Avner Friedman and Walter Littman. Visitors who plan to attend are requested to inform Dr. Friedman.

The seminar meets in Vincent Hall 570

Friday, November 4

SEMINAR ON INDUSTRIAL PROBLEMS

11:15 am	**Kwok Tam** General Electric	Cone-beam 3D CT image reconstruction

The SEMINAR meets in Vincent Hall 570

Monday, November 7

SEMINAR IN { **Math/Physics**
Room VinH 570 }

3:30 pm	**Jeffrey Ondich** Carleton College	Partial invariance

Organizer: Peter Olver

Tuesday, November 8

Election Day

IMA Postdoc Seminar

2:30 pm	**Vojkan Jaksic** IMA	The approach to Equilibrium in Quantum Mechanics

Organizer: Erding Luo

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

IMA Tutorial:

Waves in Random and Other Complex Media

November 9 - 10, 1994
Speakers: Leonid Pastur and Benjamin White

Unless otherwise noted, tutorial talks will be held in the Seminar Room, Vincent Hall 570

Wednesday, November 9

9:15 am	**Welcome, Orientation, Overview**	A. Friedman, R. Gulliver, G. Papanicolaou
9:30 am	**Leonid Pastur** Academy of Sciences of Ukraine	Localisation Theory: Basic Ideas and Results I

Abstract: This part of the tutorial lectures will present an introduction to localization theory, which studies the point spectrum of differential or finite-difference equations with random coefficients. These equations model various processes in randomly inhomogeneous media. We start from the one-dimensional case defining the integrated density of states (IDS) and the Lyapunov exponent (LE), proving their existence for arbitrary ergodic coefficients of the respective equations, demonstrating their simplest important properties (differentiability of the IDS and positivity of the LE), and explaining the multiplicative ergodic theorem. Then we prove the exponential localisation (pure point spectrum with exponentially decaying eigenfunctions) for the one-dimensional discrete Schrödinger equation with independent smoothly distributed potential. We also mention some implications of this result for the propagation of waves and particles through long random barriers. We conclude outlining a widely accepted scheme of localisation theory and some multidimensional results.

11:00 am	**Leonid Pastur** Academy of Sciences of Ukraine	Localisation Theory: Basic Ideas and Results II
2:00 pm	**Leonid Pastur** Academy of Sciences of Ukraine	Localisation Theory: Basic Ideas and Results III
4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Thursday, November 10

9:30 am	**Benjamin S. White** Exxon Corporate Research	Asymptotic Methods for Stochastic Differential Equations, with Application to Wave Propagation in Random Media I

Abstract: In these lectures, I will present asymptotic methods for the analysis of stochastic differential equations with a small parameter, and apply them to selected problems of wave propagation in random media. Topics will include: review of Markov process theory, infinitesimal generators, the Ito calculus and diffusions; an introduction to mixing processes, Central Limit Theorems for stochastic differential equations with a small parameter, and convergence to diffusion process limits (i.e. Stratonovich calculus); application to low frequency wave propagation in randomly-stratified media, including localization theory and the spectral analysis of backscatter; and application to high frequency wave propagation in smooth random media,

11:00 am	**Benjamin S. White** Exxon Corporate Research	Asymptotic Methods for Stochastic Differential Equations, with Application to Wave Propagation in Random Media II
2:00 pm	**Benjamin S. White** Exxon Corporate Research	Asymptotic Methods for Stochastic Differential Equations, with Application to Wave Propagation in Random Media III

Friday, November 11

SEMINAR IN { **Mathematical Physics**
Room VinH 570

2:30 pm **Barbara Abraham-Shrauner** Washington University — Hidden Symmetries of Ordinary Differential Equations

Abstract: Type II hidden symmetries, those lost when the order of an ODE is reduced, have been found to occur in three ways recently. First, these hidden symmetries arise if an ODE, invariant under a solvable, nonabelian three-parameter Lie group, is reduced in order along some paths. Second, an ODE invariant under point and contact symmetries may upon reduction in order have such a hidden symmetry. Third, solvable structures may be used to find some type II hidden symmetries. Focus will be on the first two cases of type II hidden symmetries.

Organizer: Peter Olver

IMA Workshop:

Waves in Random and Other Complex Media

November 14 - 18, 1994

Organizers: Robert Burridge, George Papanicolaou and Leonid Pastur

Unless otherwise noted, workshop talks will be held in the Lecture Hall, EE/CS 3-180

The main thrust of this workshop is to study the effects of inhomogeneities on wave propagation both theoretically and computationally. This includes the following topics:

- Long wave propagation in periodic and random media.
- Effective media theory and homogenization.
- Nonlinear wave propagation.
- Waves in strongly inhomogeneous media and localization.
- Localization-transmission transition. Spectra of random operators.
- Geometrical optics (short waves) in randomly inhomogeneous media.
- Multiple scattering by discrete scatterers.
- Transport theory for waves in random media. Derivation of transport equations. Connection with radiative transport theory.
- Nonlinearity, dispersion and randomness in long wave transmission.
- Applications to optical fibers.
- Reflection and transmission of waves by nonlinear random media. Competition between nonlinearity (focusing-defocusing) and randomness (localization-transport).
- Applications to radio wave propagation in the atmosphere, sound propagation in the ocean and seismic wave propagation in the earth.

Monday, November 14

9:15 am	**Welcome, Orientation, Overview**	A. Friedman, R. Gulliver, G. Papanicolaou
9:30 am	**Leonid Pastur** Academy of Sciences of Ukraine	To be announced
10:30 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00 am	**Benjamin S. White** Exxon Corporate Research	Localization and Mode Conversion For Elastic Waves in Randomly-Stratified Media

Abstract: We derive localization theory for elastic waves in plane-stratified media, a multimode problem complicated by the inter-conversion of shear and compressional waves, both in propagation and in backscatter. We solve this problem for two typical limiting cases: (1) the low frequency limit, i.e. when the randomness constitutes a microstructure, and (2) the small fluctuation limit, i.e. when the amplitude of the random fluctuations is small. In both cases we give analytical expressions for the following quantities: the localization length, and another deterministic length, called the equilibration length, which gives the scale for the equilibration of compressional and shear energy in propagation; the probability density for the fraction of reflected energy which remains in the same mode (shear or compressional) as the incident field; and the probability density of shear to compressional energy in transmission through a large slab. This last quantity is shown to be asymptotically independent of the incident field. Our main mathematical tools are: the Oseledec theorem, which gives the existence of the localization length, and other structural information; and limit theorems for stochastic differential equations with a small parameter.

This work is in collaboration with W. Kohler and G. Papanicolaou.

2:00 pm	**Fadil Santosa** University of Delaware	Wave Propagation in Periodic Composites

Abstract: We present an overview of some recent progress in modeling wave propagation in periodic composites. We begin with an approximation based on the Bloch expansion. It is able to capture accurately the wave dispersion, a predominant phenomenon after large travel distances/times. We will also review some results pertaining to propagation in bounded regions. The main findings will be illustrated in numerical examples.

3:00 pm	**Maarten V. De Hoop** Schlumberger Cambridge Research	To be announced

SEMINAR IN { **Mathematical Physics**
Room VinH 570 }

3:30 pm	**Satyanad Kichenassamy** University of Minnesota	To be announced

Organizer: Peter Olver

4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Tuesday, November 15

9:30 am	**Thomas Spencer** Institute for Advanced Study	Rigorous scaling and approach to the mobility edge

Abstract: We describe a rigorous scaling for transport for random Schrödinger operators. Above four dimensions we also obtain a perturbative representation for the density of states which yields good estimates on the location of the mobility edge.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00 am	**Roger Maynard** Université Fourier, Grenoble	Multiple scattering of light in random media: the "weak localization" correction to the radiative transport theory

Abstract: The propagation of waves in random media is described by the basic equations — the Dyson and the Bethe-Sapeter equations — for the configuration averages of the amplitudes and the intensities. The random interference pattern — the speckle — disappears when the average is performed, except for an ultimate constructive interference in the backscattering direction. The enhancement of light intensity comes from the existence of both direct and time reversal sequences of scattering of equal weight in the backward direction. This symmetry founded on the reciprocity principle, can be broken by a magnetic field acting on the polarization of the electromagnetic field and producing the Faraday effect. Recent experiments have generated new interest in the theory of this basic phenomenon. Non linear interactions of the Kerr type could change the triangular shape of the backscattering cone into a compressed sharp peak. Closely related are the recent progress in the analysis of the angular or frequency correlations of the speckle pattern as well as the time correlation of the fluctuating diffuse intensity due to the motion of the scattering centers.

2:00 pm	**Roger Dashen** U of California-San Diego	To be announced
3:00 pm	**Coffee Break** Reception Room EE/CS 3-176	
3:30 pm	**Andrei Marchenko**	To be announced
4:00 pm	**R. S. Wu** Univ. of California at Santa Cruz	
4:30 pm	**Haruo Sato** Tohoku University	Study of seismogram envelopes based on energy transport theory

Abstract: High-frequency seismograms of local earthquakes are well characterized by their smooth envelopes, which mostly consist of incoherently scattered waves due to inhomogeneities in the earth medium. In the framework of the energy transport theory, or the radiative transfer theory, we may describe the propagation of seismic energy spherically radiated from a point source through a scattering medium, in which point-like scatterers are distributed homogeneously and randomly. We introduce a Green function which represents a causal propagation and geometrical spreading with scattering and intrinsic attenuation. At first, supposing isotropic scattering, we show a formulation of multiple scattering process with P-S conversions in order to explain the general characteristics of whole seismogram envelopes of local earthquakes starting from P wave onset to S coda. Next, extending the isotropic scattering process, we formulate the multiple non-isotropic scattering process. In the case of large forward scattering, we find a concentration of energy density just after the direct wave front, and a spatially uniform distribution of energy density around the source location at long lapse times. Third, we formulate the multiple isotropic scattering process in a scattering medium in which the distributions of scatterers and intrinsic absorbers are random and fractally homogeneous. It is well known that the hypocenter distribution of micro-earthquakes is fractal, therefore, it is natural to examine such a possibility. When the fractal dimension

is two for intrinsic absorbers, we can derive a power law decay of the direct energy density with travel distance.

Wednesday, November 16

9:30 am	**William L. Kath** Northwestern University	Long-term storage of a soliton bit stream using phase-sensitive amplification

Abstract: Long-term storage of a soliton bit stream in a fiber ring in which loss is compensated by phase-sensitive amplification is investigated. Included in the model are a semi-classical approximation of the quantum fluctuations present in such a fiber ring, as well as phase noise generated by guided acoustic-wave Brillouin scattering (GAWBS). It is shown that the one's (soliton pulses) are asymptotically stable and the noise on the zero's of the bit stream (absence of a soliton) is bounded. Moreover, the soliton-soliton interaction is efficiently suppressed by the phase-sensitive amplifiers.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	

11:00 am	**Ross C. McPhedran** University of Sydney	Green's function, lattice sums and rayleigh identity for a dynamic scattering problem

Abstract: We have recently exhibited expressions for Green's functions for dynamic scattering problems for gratings and arrays, expressed in terms of lattice sums. We have also discussed new ways to evaluate these sums, and how their use in Green's function forms leads naturally to Rayleigh identities for scattering problems. These Rayleigh identities express connections between regular parts of wave solutions near a particular scatterer, and irregular parts of the solution summed over all other scatterers in a system. Here, we will discuss these ideas and techniques in the context of the problem of the scattering of a scalar wave by a regular lattice of spheres. We will discuss expressions for lattice sums which can be integrated arbitrarily-many times to accelerate convergence, a computationally-efficient Green's function form, and the appropriate Rayleigh identity for the problem. We will also discuss the long-wavelength limit, in which the dynamic identity tends to the static identity in a mathematically interesting way. Joint work with N. Nicorovici and Bao Ke-Da.

2:00 pm	**Costa M. Soukoulis** Iowa State University	Propagation of classical waves: a search for Anderson localization

Abstract: In spite of the extensive attention that the question of classical wave localization has received recently, there is no conclusive evidence yet that classical-wave localization is indeed possible in disordered systems characterized by a positive definite random dielectric function. The various calculational methods for studying the problem of optical localization will be briefly presented. The important differences in the formulation of the theory of localization for classical waves will be discussed, and the low density approximation of the energy transport velocity enetering the diffusion coefficient will be given. Explicit results based on a Coherent Potential Approximation recently developed by Economou and Soukoulis will be presented, discussed and compared with recent experimental observations.

3:00 pm	**Coffee Break** Reception Room EE/CS 3-176	

Thursday, November 17

9:30 am	**Kenneth Golden** University of Utah	The Interaction of Microwaves with Sea Ice

Abstract: Sea ice, or frozen sea water, in the polar regions plays a major role in global climate as the boundary layer between the ocean and atmosphere. Due to its vast extent, properties of the sea ice pack are often studied

via electromagnetic remote sensing from satellites and airplanes, in the microwave regime. In this talk, we will discuss ongoing mathematical and experimental investigations of the interaction of microwaves with sea ice. This interaction is particularly interesting in the case of sea ice, which consists of pure ice with random brine and air inclusions whose geometry can depend dramatically on temperature. In particular, we shall present bounds on the effective complex permittivity of sea ice, and compare these bounds with experimental data. We shall pay particular attention to an apparent discrepancy between the bounds and the data as the quasi-static assumption breaks down with higher frequencies. Also, we shall discuss the effect of the connectedness of the brine phase on the electromagnetic behavior of the ice, since above around -6 degrees C the brine pockets tend to coalesce, or percolate, and the sea ice becomes porous.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00 am	**George Papanicolaou** Stanford University	Transport equations for waves.

Abstract: We review the validity of transport theory for wave propagation in randomly inhomogeneous media. We present some recent work on elastic waves that shows the effects of polarization and mode coupling. We examine connections with the regime where waves localize.

2:00 pm	**Aleksander Figotin** University of North Carolina	To be announced
2:30 pm	**Jean-Pierre Fouque** Unite de Recherche Associee au CNRS	To be announced
3:00 pm	**Coffee Break** Reception Room EE/CS 3-176	
3:30 pm	**Yuri Kivshar** Australian National University	To be announced
4:00 pm	**Valentin Freilikher** Bar-Ilan University	To be announced
4:30 pm	**To be announced**	
6:30 pm	**Workshop Dinner**	Holiday Inn Metrodome

Friday, November 18

8:45 am	**Sergey A. Gredeskul** Ben Gurion Univ. of Negev	Electrons in a two-dimensional system with random point scatterers and magnetic field

Abstract: Dynamics of an electron in a magnetic field and field of disordered point impurities is studied. The case of a single impurity is completely solved. The conditions when a short-range scatterer in the presence of a magnetic field can be replaced by a point scatterer are determined. The regions of energy and magnetic field, where such a replacing is possible, are found. For the case of infinite number of impurities the pertinent equations

for the eigenvalues and eigenfunctions are derived; these equations coincide with ones for Lifshits model (in a magnetic field). For the site-disordered system it is shown that at each of the Landau energies, starting from a certain value of magnetic field there exist disorder independent extended eigenstates. These wave functions are given analytically in closed form.

9:45 am	**Coffee Break** Reception Room EE/CS 3-176	
10:00 am	**Stanislav Molchanov** Univ. of North Carolina at Charlotte	Wave and heat processes in the random or fractal boudary layer

Abstract: A very thin covering layer can change radically the physical properties of the material. Especially important are the phenomena of the absorption of the heat energy or short waves (heat insulation, vibrostability, etc.). This lecture will contain a review of the recent mathematical results in the cases of fractal or random boundary layers as well as a discussion of the possible physical and technical applications.

SEMINAR ON INDUSTRIAL PROBLEMS

11:00 am	**Coffee Break** IMA Lounge, Vincent Hall 502	
11:15 am	**Emmanuel M. Tsimis** General Motors	Global geodesic coordinate system on a GO-continuous surface

Abstract: The design, analysis, and manufacturing of parts in the automobile, ship, and airplane industries require one to do geometrical operations on connected, compact, orientable surfaces of GO-continuity, possibly trimmed with inner boundaries. Those operations would be greatly facilitated if we had a global geodesic coordinate system on the surface, where the constant coordinate curves are minimum-distance paths on the surface.

In case the surface is analytic, then we have well-established theories for determining a global geodesic coordinate system. We are interested in determining such a system on surfaces represented by a collection of mappings each of which is analytic, and the analytic pieces are placed together with GO-continuity across their common boundaries. A polyhedron is a special case.

Inherent to this problem is that of determining the minimum-distance path connecting two given points on the surface.

The SEMINAR meets in Vincent Hall 570

2:00 pm	**Robert Burridge** Schlumberger - Doll Research	To be announced

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Monday, November 21

SEMINAR IN { **Math/Physics** / **Room VinH 570** }

3:30 pm	**Peter Olver** Univ. of Minnesota	Non-associative Lie groups

Abstract: A general method for constructing local Lie groups which are not contained in any global Lie group is described. All the examples fail to satisfy the generalized associativity axiom which, by a theorem of Mal'cev, is

necessary and sufficient for globalizability. Furthermore, we prove that every local Lie group is contained in one of these examples, thereby generalizing Cartan's global version of the Third Fundamental Theorem of Lie.

Organizer: Peter Olver

Tuesday, November 22

SEMINAR IN { **Numerical Analysis**
Vincent Hall 570

11:15 am **To be announced**

Mitch Luskin, Organizer

IMA Postdoc Seminar

2:30 pm	**Robert Acar** Eastern Montana College	Using BV functions for Ill-posed Problems

Organizer: Erding Luo

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

Wednesday, November 23

SEMINAR IN { **Math/Physics**
Room VinH 570

Thursday, November 24

Thanksgiving Day: University of Minnesota holiday. IMA offices will be closed.

Friday, November 25

University of Minnesota holiday. IMA offices will be closed.

CURRENT IMA PARTICIPANTS

POSTDOCTORAL MEMBERS FOR 1994-95 PROGRAM YEAR

NAME	PREVIOUS/PRESENT INSTITUTION
Bronski, Jared C.	Princeton University
Jaksic, Vojkan	University of Kentucky
Kargol, Armin	VPI&SU
Kim, Dai-Gyoung	Purdue University
Liu, Changmei	University of Rochester
Luo, Erding	UCLA
Patch, Sarah	UC Berkeley
Yu, Shih-Hsien	Stanford University

POSTDOCTORAL MEMBERSHIPS IN INDUSTRIAL MATHEMATICS FOR 1994-95

NAME	PREVIOUS/PRESENT INSTITUTION
Cockburn, Juan C.	University of Minnesota
Copeland, Mark A.	Clemson University
Huntley, Douglas	Northwestern University
Kutz, Jose Nathan	Northwestern University
Nitsche, Monika	University of Colorado

CNRS POSTDOCTORAL MEMBER FOR 1994-95

NAME	PREVIOUS/PRESENT INSTITUTION
Ponenti, Pierre-Jean	Physique Théorique Marseille

VISITORS IN RESIDENCE (as of 9/29)

Acar, Robert	Eastern Montana College	SEP 1 - AUG 31
Berlyand, Leonid	Penn State University	NOV 13 - 18
Berryman, James G.	Lawrence Livermore Nat. Laboratory	NOV 13 - 18
Beylkin, Gregory	University of Colorado	SEP 6 - DEC 15
Boutet De Montvel, Ann	University of Paris VII	NOV 10 - 25
Burridge, Robert	Schlumberger-Doll Research Center	SEP 1 - MAR 31
Carmona, Rene	U of California-Irvine	NOV 13 - 18
Cheney, Margaret	RPI	AUG 15 - JUN 15
Dashen, Roger	U of California-San Diego	NOV 13 - 18
De Hoop, Martijn	Schlumberger-Cambridge Research	NOV 1 - 30
Dessing, Frank	Delft University of Technology	NOV 6 - 19
Figotin, Aleksander	University of North Carolina	NOV 13 - 20
Fouque, Jean-Pierre	Unite de Recherche Associee au CNRS	NOV 12 - 18
Freilikher, Valentin	Bar-Ilan University	NOV 13 - 18
Friedman, Avner	IMA	
Golden, Kenneth M.	University of Utah	NOV 13 - 18
Gredeskul, Sergey	Ben Gurion University of Negev	NOV 13 - 18
Gulliver, Robert	IMA	
Herrmann, Felix J.	Delft University of Technology	NOV 6 - 19
Horn, Mary Ann	University of Minnesota	SEP 1 - AUG 31
Kichenassamy, Satyanad	University of Minnesota	SEP 1 - JUN 30
Kim, Jeong	Iowa State University	NOV 14 - 18
Kivshar, Yuri	The Australian National University	NOV 13 - 18
Kohler, Werner E.	VPI & SU	NOV 13 - 18
Kreiss, Heinz-Otto	U of California-Los Angeles	SEP 18 - DEC 18
Kriegsmann, Gregory A.	New Jersey Institute of Technology	SEP 7 - DEC 20
Levine, Howard	Iowa State University	OCT 3 - DEC 16
Littman, Walter	University of Minnesota	SEP 1 - JUN 30
Malkin, Vladimir M.	Courant Institute	SEP 1 - DEC 1
Marchenko, Vladimir M.	Byelorussian Institute of Technology	NOV 13 - 18
Maynard, R.	Universite Joseph Fourier	NOV 13 - 18
Mcphedran, Ross C.	University of Sydney	NOV 13 - 18
Molchanov, Stanislav	University of North Carolina	NOV 13 - 20
Nakajima, Toshiya	Fujitsu Ltd.	OCT 2 - DEC 30
Ni, Wei-Ming	University of Minnesota	SEP 1 - JUN 30
Papanicolaou, George	Stanford University	NOV 14 - 17
Pastur, Leonid	Academy of Science of Ukraine	SEP 23 - DEC 22
Postel, Marie	Universite Pierre et Marie Curie	NOV 13 - 18
Rejto, Peter	University of Minnesota	SEP 1 - JUN 30
Ryzhik, Leonid	Stanford University	NOV 9 - 18
Santosa, Fadil	University of Delaware	NOV 12 - 16

Sato, Haruo	Tohoku University	NOV 13 - 18
Sattinger, David	University of Minnesota	SEP 1 - JUN 30
Shaw, Frank	U of California-Riverside	JAN 1 - DEC 31
Soukoulis, C.	Iowa State University	NOV 13 - 18
Spencer, Thomas	Institute for Advanced Studies	NOV 13 - 18
Stickler, David	New Jersey Institute of Technology	NOV 13 - 20
Stork, Christof	Advance Geophysical Corporation	MAR 6 - 17
Sverak, Vladimir	University of Minnesota	SEP 1 - JUN 30
Tam, Kwok	General Electric	NOV 3 - 4
Tsimis, Emmanuel	Electric Data Systems	NOV 17 - 18
Wai, Alexander Ping-Kong	University of Maryland	NOV 13 - 18
White, Benjamin S.	Exxon	NOV 1 - 30
Wu, R.S.	University of California at Santa Cruz	NOV 13 - 18
Zirilli, Francesco	Universita di Roma "La Sapienza"	SEP 1 - JUN 30

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IMA NEWSLETTER # 222

November 27–December 31, 1994

1994-95 Program
WAVES AND SCATTERING

See the Fall 1994 IMA Update for a full description of the 1994 - 95 program on Waves and Scattering

News and Notes

New Members chosen by Board of Governors

At its meeting in Minneapolis on October 9, the Board of Governors of the IMA elected four new members, who have agreed to serve on the board for three years beginning January 1, 1995. They are **Mary Ellen Boch** of Purdue University, **David Levermore** of the University of Arizona, **James McKenna** of Bellcore and **Alan Perelson** of Los Alamos National Laboratory. Retiring members are Ingrid Daubechies of AT&T Bell Laboratories and Princeton University, Alan Hoffman of IBM Watson Research Center, Mac Hyman of Los Alamos National Laboratories and Gary C. McDonald of General Motors.

Schedule for November 27 – December 31, 1994

Monday, November 28

11:15 am	**Heinz-Otto Kreiss** UCLA	Numerical boundary conditions for hyperbolic and parabolic partial differential equations, I

This is the first of four talks, Monday through Thursday, comprising a short course.

SEMINAR IN { **Mathematical Physics** / **Room VinH 570** }

3:30 pm	**Jianduan Chen** University of Minnesota	The χ Invariant of Connes and Cohomology of Groups

Abstract: In classifying automorphisms of von Neumann algebras, Alain Connes discovered an invariant for von Neumann algebras in mid-70's. This is an abelian normal subgroup (called χ) in the quotient of the full automorphism group of the algebra by the inner automorphism group. There are two more algebraic invariants associated with χ: a quadratic form (discovered by Vaughan Jones and Colin Sutherland in early 80's) and a third cohomology class on χ, both taking values in the unit circle. We show that the quadratic form is a finer invariant than the cohomology class. We realize all quadratic forms on finite abelian groups. Our method relies on the cohomology theory of groups. In fact certain new results of purely algebraic nature relating quadratic forms and cohomology of perfect groups are discovered through this motivation from von Neumann algebras. Of particular importance are examples of amenable perfect groups with certain cohomological properties.

Organizer: Peter Olver

Tuesday, November 29

11:15 am	**Heinz-Otto Kreiss** UCLA	Numerical boundary conditions for hyperbolic and parabolic partial differential equations, II

IMA Postdoc Seminar

2:30 pm	**Howard Levine** Iowa State University	Critical Exponents of Fujita Type

Organizer: Erding Luo

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

Wednesday, November 30

11:15 am	**Heinz-Otto Kreiss** UCLA	Numerical boundary conditions for hyperbolic and parabolic partial differential equations, III

Thursday, December 1

11:15 am	**Heinz-Otto Kreiss** UCLA	Numerical boundary conditions for hyperbolic and parabolic partial differential equations, IV

IMA Industrial Postdocs Seminar

The seminar will meet from 1:00 pm – 5:00 pm today. The format of the seminar is:

1. Presentation of projects and problems from industry (Honeywell, Siemens, 3M and Unisys) on which the industrial postdocs are working.
2. Informal suggestions and discussion among the participants.

The seminar is directed by Avner Friedman and Walter Littman. Visitors who plan to attend are requested to inform Dr. Friedman.

Friday, December 2

SEMINAR ON INDUSTRIAL PROBLEMS

11:15 am	**L. Craig Davis** Ford Motor Co., Dearborn	Micromechanics Effects in Creep of Metal-Matrix Composites

Abstract: When placed under tensile loading, metals tend to creep, or elongate slowly over times of order hours to days. The creep rate is proportional to *en* where e is the applied stress and n is typically in the range $2 < n < 15$. If non-creeping, reinforcing particles are added to the metal, the creep rate of the composite is substantially reduced. In the present work, the creep of metal-matrix composites is analyzed by finite element techniques. An axisymmetric unit-cell model with spherical reinforcing particles is used. Parameters appropriate to ceramic particles in an aluminum matrix are chosen. The effects of matrix plasticity on the creep of the composite are calculated. The principal results of these calculations are: (1) that the steady-state creep rate of the composite is proportional to *en* with the same exponent n as specified for the unreinforced matrix, (2) that the steady-state rate is independent of the particle elastic moduli and the matrix elastic/plastic properties, (3) that the ratio of composite to matrix steady-state creep rates depends only on the volume fraction and geometry of the reinforcing phase, and (4) that this ratio can be determined from a calculation of the stress-strain relation for the geometrically identical composite (same phase volume and geometry) with rigid particles in the appropriate power-law hardening matrix. Rigorous and complete proofs of these properties apparently do not exist in the literature.

The SEMINAR meets in Vincent Hall 570

Monday, December 5

Joint IMA–MCIM Colloquium in Room Vin H 570

3:30 pm	**Craig Poling** Paramax Corporation	Dual Use of Sonar in Industry

Wednesday, December 7

3:00 pm	**IMA Holiday Party**	Rooms Vin H 502 and 570

IMA participants and their families are invited!

Please bring your favorite party food to share. The IMA will be providing the beverages.

Set-up will start at 2:45 pm. Please bring your food contributions to Vincent Hall 570 between 2:45 and 3:00 (remember to take your dish when you leave.)

Remember to sign up on the list posted in the lounge, Vincent Hall 502, by Friday, December 2. Food suggestions will be listed there also.

CURRENT IMA PARTICIPANTS

POSTDOCTORAL MEMBERS FOR 1994-95 PROGRAM YEAR

NAME	PREVIOUS/PRESENT INSTITUTION
Bronski, Jared C.	Princeton University
Jaksic, Vojkan	University of Kentucky
Kargol, Armin	VPI&SU
Kim, Dai-Gyoung	Purdue University
Liu, Changmei	University of Rochester
Luo, Erding	UCLA
Patch, Sarah	UC Berkeley
Yu, Shih-Hsien	Stanford University

POSTDOCTORAL MEMBERSHIPS IN INDUSTRIAL MATHEMATICS FOR 1994-95

NAME	PREVIOUS/PRESENT INSTITUTION
Cockburn, Juan C.	University of Minnesota
Copeland, Mark A.	Clemson University
Huntley, Douglas	Northwestern University
Kutz, Jose Nathan	Northwestern University
Nitsche, Monika	University of Colorado

CNRS POSTDOCTORAL MEMBER FOR 1994-95

NAME	PREVIOUS/PRESENT INSTITUTION
Ponenti, Pierre-Jean	Physique Théorique Marseille

VISITORS IN RESIDENCE (as of 11/8)

Acar, Robert	Eastern Montana College	SEP 1 - AUG 31
Beylkin, Gregory	University of Colorado	SEP 6 - DEC 15
Burridge, Robert	Schlumberger-Doll Research Center	SEP 1 - MAR 31
Cheney, Margaret	RPI	AUG 15 - JUN 15
Davis, Craig	Ford Motor Company	DEC 1 - 2
Horn, Mary Ann	University of Minnesota	SEP 1 - AUG 31
Kichenassamy, Satyanad	University of Minnesota	SEP 1 - JUN 30
Kreiss, Heinz-Otto	Univ. of Calif. Los Angeles	SEP 18 - DEC 18
Kriegsmann, Gregory A.	New Jersey Institute of Technology	SEP 7 - DEC 20
Levine, Howard	Iowa State University	OCT 3 - DEC 16
Littman, Walter	University of Minnesota	SEP 1 - JUN 30
Malkin, Vladimir M.	Courant Institute	SEP 1 - DEC 31
Nakajima, Toshiya	Fujitsu Ltd.	OCT 10 - DEC 28
Ni, Wei-Ming	University of Minnesota	SEP 1 - JUN 30
Pastur, Leonid	Ukraine Academy of Sciences	SEP 23 - DEC 8
Rejto, Peter	University of Minnesota	SEP 1 - JUN 30
Sattinger, David	University of Minnesota	SEP 1 - JUN 30
Shaw, Frank	U of California-Riverside	JAN 1 - DEC 31
Stork, Christof	Advance Geophysical Corporation	MAR 6 - 17
Sverak, Vladimir	University of Minnesota	SEP 1 - JUN 30
Zirilli, Francesco	Universita di Roma "La Sapienza"	SEP 1 - JUN 30

INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

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anonymous ftp: ftp.ima.umn.edu, gopher: gopher.ima.umn.edu, www: http://www.ima.umn.edu

IMA NEWSLETTER # 223

January 1–28, 1995

1994-95 Program
WAVES AND SCATTERING

News and Notes

NOTE: DATES FOR THE TUTORIAL HAVE BEEN CHANGED

IMA Tutorial:

Inverse Problems in Electromagnetic Wave Propagation

January 18–20, 1995
Speakers: David Colton, Adel Faridani and George Papanicolaou

Weekly IMA seminar list now available by list server

The IMA is happy to announce its new e-mail mailing list service. Currently we offer the mailing list "weekly" which is a distribution of the schedule of IMA seminars and events. If you wish to subscribe to this list, simply send an e-mail message to imalists@ima.umn.edu whose first line is of the form

subscribe weekly

If you have a preferred e-mail address other the one from which you are sending the request, the first line should be

subscribe weekly you@e.mail.address

The subject line is ignored. Questions or problems should be sent to owner-weekly@ima.umn.edu.

The same weekly schedule will still be available on request via finger seminar@ima.umn.edu; the new list server e-mails the list each Thursday for the following week. An updated .dvi file of this newsletter (current and recent) is also available through Mosaic.

PARTICIPATING INSTITUTIONS: Centre National de la Recherche Scientifique, Consiglio Nazionale delle Ricerche, Georgia Institute of Technology, Indiana University, Iowa State University, Kent State University, Michigan State University, Northern Illinois University, Northwestern University, Ohio State University, Pennsylvania State University, Purdue University, Seoul National University (RIM - GARC), Texas A&M University, University of Chicago, University of Cincinnati, University of Houston, University of Illinois (Chicago), University of Illinois (Urbana), University of Iowa, University of Kentucky, University of Manitoba, University of Maryland, University of Michigan, University of Minnesota, University of Notre Dame, University of Pittsburgh, University of Southern California, University of Wisconsin, Wayne State University.

PARTICIPATING CORPORATIONS: Bellcore, Cray Research, Eastman Kodak, EPRI, Ford, General Motors, Honeywell, IBM, Kao, Motorola, UNISYS, Siemens, 3M.

Schedule for January 1–28, 1995

Monday, January 2

University of Minnesota holiday. The IMA offices will be closed.

Tuesday, January 3

IMA Postdoc Seminar

2:30 pm **To be announced**

Organizer: S. Patch

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

Wednesday, January 4

Thursday, January 5

IMA Industrial Postdocs Seminar

The seminar will meet from 1:00 pm – 5:00 pm today. The format of the seminar is:

1. Presentation of projects and problems from industry (Honeywell, Siemens, 3M and Unisys) on which the industrial postdocs are working.
2. Informal suggestions and discussion among the participants.

The seminar is directed by Avner Friedman and Walter Littman. Visitors who plan to attend are requested to inform Dr. Friedman.

Friday, January 6

SEMINAR ON INDUSTRIAL PROBLEMS

11:15 am **Robert Burridge** Seismic inversion for geophysical prospecting
Schlumberger-Doll Research

Abstract: For the purposes of oil exploration impulses of seismic waves are generated by a source at the ground surface and the backscattered vibrations are received by an array of geophones laid out also on the ground surface. The signal from each receiver as a function of time is recorded digitally for later processing. Typically a seismic 'survey' consists of many such 'source gathers' for many different positions of the source and receiver array.

Treating the earth as an elastic medium the problem is to deduce the elastic parameters of the subsurface material and its density as functions of position from the data recorded at the surface. Typically our data is deficient in the sense that, since sources and receivers are on the surface, there is only a limited range of 'viewing' directions and we cannot recover the material parameters with as high resolution as we would like. Mathematically the problem is an inverse problem in elastic wave scattering, the forward problem being the elastic diffraction problem of predicting the responses of the receivers when the source and the properties of the medium are known.

We linearize the inverse problem and consider various degrees of sophistication. The most naive approximation is to treat the earth as an elastic fluid. Next in sophistication is to treat it as an isotropic elastic medium and then as an anisotropic elastic medium. When the data is complete one may use the theory of the Radon transform. Otherwise, we make up for deficiences in the data by making use of prior geological information, such as the fact that the earth is layered with a field of normals defined everywhere.

Ray theory and high frequency approximations are used extensively.

The SEMINAR meets in Vincent Hall 570

Monday, January 9

SEMINAR IN { **Mathematical Physics**
VinH 570 }

3:30 pm **To be announced**

Organizer: Peter Olver

Tuesday, January 10

SEMINAR IN { **Numerical Analysis**
Vincent Hall 570 }

11:15 am **To be announced**

Mitch Luskin, Organizer

IMA Postdoc Seminar

2:30 pm **Monika Nitsche** Computation of vortex-sheet motion
IMA/University of Colorado

Abstract: Vortex sheet motion is subject to Kelvin/Helmholtz instability and spiral roll-up. The vortex blob method addresses the numerical difficulties thus created by regularizing the governing equations. We will apply the vortex blob method to compute the formation process of vortex rings. Comparison with experimental measurements as well as theoretical predictions for the formation process will be presented to validate the numerical results.

Organizer: S. Patch

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

SEMINAR IN { **Combinatorics**
Vincent Hall 570 }

4:40 pm **To be announced** To be announced

Victor Reiner, Organizer

Wednesday, January 11

Thursday, January 12

Friday, January 13

SEMINAR ON INDUSTRIAL PROBLEMS

11:15 am	**James Cavendish** General Motors Research Labs	The mathematics of surface modeling: impacts of design and manufacturing

Abstract: In industry today, product designers often model complex surfaces such as sheet-metal panels, plastic containers and optical lenses on CAD systems.

These mathematical surfaces then become the starting point for important downstream applications including computer-aided engineering (for example, finite-element structural analysis) and manufacturing (for example, NC programming). Despite the importance of manufacturing applications, the concerns related primarily to product design have usually driven the specific mathematics and computational approaches used to represent surfaces. Consequently, surfacing mathematics developed for product design has not always produced representations good for manufacturing. The speaker will describe how design and manufacturing issues have together defined the mathematics and computer algorithms used to design and represent multi-featured surfaces at General Motors.

The SEMINAR meets in Vincent Hall 570

Monday, January 16

University of Minnesota holiday. The IMA offices will be closed.

Tuesday, January 17

SEMINAR IN { **Numerical Analysis** / **Vincent Hall 570** }

11:15 am	**To be announced**

Mitch Luskin, Organizer

IMA Postdoc Seminar

2:30 pm	**S. K. Patch** IMA/U. of California, Berkeley	*-division in Diffuse Tomography

Abstract: Computing forward solutions in transport theory, and more recently "diffuse tomography", often requires computing the Redheffer *-product for large systems. The point of any tomographic technique, however, is to solve the inverse problem. After describing the model *-division will be used to break a large system into smaller systems. Finally, particular *-divisors will be used to derive a lower bound on the number of independent range conditions upon the *-product for systems in the plane.

Organizer: S. Patch

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

SEMINAR IN { **Combinatorics** / **Vincent Hall 570** }

4:40 pm	**To be announced**	To be announced

Victor Reiner, Organizer

NOTE: DATES FOR THE TUTORIAL HAVE BEEN CHANGED

IMA Tutorial:

Inverse Problems in Electromagnetic Wave Propagation

January 18–20, 1995

Speakers: David Colton, Adel Faridani and George Papanicolaou

Wednesday, January 18

Talks today are in the Seminar Room, Vincent Hall 570

9:00 am	**Registration and Coffee**	VinH 514 and IMA Lounge, VinH 502
9:30 am	**Welcome and Orientation**	A. Friedman, R. Gulliver
9:45 am	**David Colton** University of Delaware	Inverse Scattering Problems for Electromagnetic Waves I

Abstract: This series of lectures will consider inverse problems associated with the scattering of time-harmonic electromagnetic waves by a bounded object. We will consider the case when the scattering object has finite conductivity as well as infinite conductivity (*i.e.*, a perfect conductor), concentrating on results obtained in the past two to three years. We will also indicate several outstanding open problems. Included in our discussion will be:

1. uniqueness theorems,
2. spectral theory of the far field operator,
3. numerical methods for solving the inverse problem and
4. an application to the problem of detecting or monitoring the growth of leukemia.

10:45 am	**Coffee Break** IMA Lounge, Vincent Hall 502	
11:15 am	**David Colton** University of Delaware	Inverse Scattering Problems for Electromagnetic Waves II
2:00 pm	**David Colton** University of Delaware	Inverse Scattering Problems for Electromagnetic Waves III
4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Thursday, January 19

Talks today are in the Seminar Room, Vincent Hall 570

9:45 am	**Adel Faridani** Oregon State University	Computerized X-Ray Tomography I

Abstract: The mathematical problem underlying X-ray tomography is the reconstruction of a function from its line integrals. The same problem arises in imaging techniques in a growing number of areas ranging from non-destructive testing to quantum optics. The lectures will provide an introduction to the field and describe some recent developments, including optimal sampling, region-of-interest tomography, and detection of singularities.

10:45 am	**Coffee Break** IMA Lounge, Vincent Hall 502	
11:15 am	**Adel Faridani** Oregon State University	Computerized X-Ray Tomography II
2:00 pm	**Adel Faridani** Oregon State University	Computerized X-Ray Tomography III
3:00 pm	**Coffee Break** IMA Lounge, Vincent Hall 502	

Friday, January 20

Talks today are in the Seminar Room, Vincent Hall 570

9:45 am	**George Papanicolaou** Stanford University	Inverse problems for waves in random media I

Abstract: In this tutorial I will begin with an overview of the inverse problem in random media: from noisy refelected signals to extract information about the properties of the medium through which the waves propagate. After this general introduction I will explain how the statistical analysis of nonstationary processes becomes a central issue and I will review and criticize the currently available methods for nonstationary spectral analysis. I will then explain in detail an adaptive spectral estimation method that is particularly well suited to locally stationary processes. This is a class of processes that is of special interest in seismology and elsewhere. The adaptive spectral analysis uses the local cosine transform. I will end by formulating several interesting open problems, both theoretical and applied.

10:45 am	**Coffee Break** IMA Lounge, Vincent Hall 502	

SEMINAR ON INDUSTRIAL PROBLEMS

11:15 am	**Satoshi Hamaguchi** IBM Watson Research Center	A shock-tracking algorithm for etch/deposition profile evolution simulations

Abstract: An understanding of the evolution of microscopic surface features under etching or deposition processes is of considerable practical importance in integrated–circuit (IC) manufacturing. In this talk, we shall discuss computational models for such surface evolution. If surface diffusion is negligible, the surface motion is governed by a Hamilton-Jacobi-like equation with appropriate entropy conditions. In our numerical method, the surface (in 2D) is represented by a piecewise-linear function and the motion of each node (*i.e.*, edge of a line segment) is regarded as the propagation of the slope discontinuity. Mathematically, such discontinuity corresponds to a shock wave, *i.e.*, a discontinuous solution of the Hamilton-Jacobi-like equation satisfying the entropy conditions. The propagation velocity of each shock wave is determined by both the shock and entropy conditions evaluated at each node (shock-tracking). Sample calculations for Cl etching of a Si surface with surface passivation (*i.e.*, simultaneous deposition of SiO_2) and Al sputter deposition into trench structures will be presented.

The SEMINAR meets in Vincent Hall 570

2:00 pm	**George Papanicolaou** Stanford University	Inverse problems for waves in random media II
3:00 pm	**Coffee Break** IMA Lounge, Vincent Hall 502	
3:30 pm	**George Papanicolaou** Stanford University	Inverse problems for waves in random media III

Monday, January 23

11:15 am	**Robert Burridge** Schlumberger-Doll Research	Waves in Anisotropic Elastic Media I

Abstract: This will be a series of three lectures on wave propagation in anisotropic elastic media, and will touch on the following topics:

1. The stiffness and the compliance tensor;
2. Plane waves in homogeneous anisotropic media;
3. The slowness surface;
4. Media with special symmetries;
5. The fundamental solution by way of plane wave expansions (the Radon transform);
6. Conical refraction; and
7. Ray theory in smoothly varying anisotropic media.

SEMINAR IN { **Mathematical Physics** / **VinH 570** }

3:30 pm **To be announced**

Organizer: Peter Olver

Tuesday, January 24

11:15 am	**Robert Burridge** Schlumberger-Doll Research	Waves in Anisotropic Elastic Media II

IMA Postdoc Seminar

2:30 pm **To be announced**

Organizer: S. Patch

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

SEMINAR IN { **Combinatorics** / **Vincent Hall 570** }

4:40 pm	**To be announced**	To be announced

Victor Reiner, Organizer

Wednesday, January 25

11:15 am	**Robert Burridge** Schlumberger-Doll Research	Waves in Anisotropic Elastic Media III

Thursday, January 26

Friday, January 27

CURRENT IMA PARTICIPANTS

POSTDOCTORAL MEMBERS FOR 1994-95 PROGRAM YEAR

NAME	PREVIOUS/PRESENT INSTITUTION
Bronski, Jared C.	Princeton University
Jaksic, Vojkan	University of Kentucky
Kargol, Armin	VPI&SU
Kim, Dai-Gyoung	Purdue University
Liu, Changmei	University of Rochester
Luo, Erding	UCLA
Patch, Sarah	UC Berkeley
Yu, Shih-Hsien	Stanford University

POSTDOCTORAL MEMBERSHIPS IN INDUSTRIAL MATHEMATICS FOR 1994-95

NAME	PREVIOUS/PRESENT INSTITUTION
Cockburn, Juan C.	University of Minnesota
Copeland, Mark A.	Clemson University
Huntley, Douglas	Northwestern University
Kutz, Jose Nathan	Northwestern University
Nitsche, Monika	University of Colorado

CNRS POSTDOCTORAL MEMBER FOR 1994-95

NAME	PREVIOUS/PRESENT INSTITUTION
Ponenti, Pierre-Jean	Physique Théorique Marseille

VISITORS IN RESIDENCE (as of 11/29)

ACAR, ROBERT	Eastern Montana College	SEP 1 - AUG 31
AKTOSUN, TUNCAY	North Dakota State University	JAN 1 - MAR 31
BURRIDGE, ROBERT	Schlumberger-Doll Research Center	SEP 1 - MAR 31
CAVENDISH, JAMES	General Motors R. & D.	JAN 12 - 13
CHAVENT, GUY	INRIA	JAN 3 - MAR 25
CHENEY, MARGARET	RPI	AUG 15 - JUN 15
CROC, ELISABETH	Universite de Provence (CNRS)	JAN 8 - MAR 31
DOBSON, DAVID	Texas A&M University	JAN 28 - FEB 3
FARIDANI, ADEL	Oregon State University	JAN 17 - 20
FINCH, DAVID	Oregon State University	JAN 2 - MAR 31
FRIEDMAN, AVNER	IMA	
GULLIVER, ROBERT	IMA	
HAMAGUCHI, SATOSHI	IBM	JAN 19 - 20
HORN, MARY ANN	University of Minnesota	SEP 1 - AUG 31

ISAACSON, DAVID	RPI	JAN 2 - MAR 31
KALNINS, ERNIE	University of Waikato	JAN 16 - 26
KICHENASSAMY, SATYANAD	University of Minnesota	SEP 1 - JUN 30
LEE, CHOON-HO	Hoseo University	DEC 15 - FEB 28
LITTMAN, WALTER	University of Minnesota	SEP 1 - JUN 30
NI, WEI-MING	University of Minnesota	SEP 1 - JUN 30
PADE, OFFER		JAN 17 - 20
PAPANICOLAOU, GEORGE	Stanford University	JAN 17 - 20
PERRY, PETER A.	University of Kentucky	JAN 15 - MAR 30
RAKESH	University of Delaware	JAN 2 - MAR 31
REJTO, PETER	University of Minnesota	SEP 1 - JUN 30
SACKS, PAUL	Iowa State University	JAN 2 - MAR 31
SATTINGER, DAVID	University of Minnesota	SEP 1 - JUN 30
SHAW, FRANK	Univ. of California-Riverside	JAN 1 - AUG 31
SOHN, WONKYU	Seoul National University	JAN 1 - MAR 31
SVERAK, VLADIMIR	University of Minnesota	SEP 1 - JUN 30
SYMES, WILLIAM	Rice University	JAN 15 - FEB 3
WRIGHT, PAUL	AT&T	JAN 26 - 27
ZIRILLI, FRANCESCO	Universita di Roma "La Sapienza"	SEP 1 - JUN 30

INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

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IMA NEWSLETTER # 224, REVISED

January 29–March 4, 1995

1994-95 Program
WAVES AND SCATTERING

News and Notes

IMA Tutorial:

Inverse Problems in Acoustic Wave Propagation

January 30–February 3, 1995
Speakers: Jan Achenbach, Christof Stork, William Symes and Margaret Cheney

Fujitsu Joins as Participating Corporation

Fujitsu Limited of Chiba, Japan joined the IMA in December, 1994 as a Participating Corporation. The IMA Participating Corporation program aims at broadening relations between university and industry mathematical scientists and identifying new mathematical research areas of interest to industry.

Weekly IMA seminar list now available by list server

The IMA is happy to announce its new e-mail mailing list service. Currently we offer the mailing list "weekly" which is a distribution each Thursday of the next week's schedule of IMA seminars and events. If you wish to subscribe, simply send an e-mail message to imalists@ima.umn.edu whose first line is of the form

```
subscribe weekly
```

If your preferred e-mail address is different from the one from which you are sending the request, the first line should be

```
subscribe weekly you@e.mail.address
```

The subject line and the rest of the message are ignored. Questions or problems should be sent to owner-weekly@ima.umn.edu.

The current weekly schedule will still be available on request via `finger seminar@ima.umn.edu`. An updated `.dvi` file of the IMA Newsletter (current and recent) is also available by `ftp` or through the world-wide web.

Schedule for January 29–March 4, 1995

IMA Tutorial:

Inverse Problems in Acoustic Wave Propagation

January 30–February 3, 1995

Speakers: Jan Achenbach, Christof Stork, William Symes and Margaret Cheney

The tutorial will concentrate on inverse problems for acoustic waves, with applications to acoustic microscopy and seismology. This week's talks, along with the talks given in the previous tutorial January 18–20, are thematically related to the IMA workshop March 6–17.

Earlier announcements listed Gunther Uhlmann of the University of Washington as a speaker; we regret that compelling circumstances made it impossible for Prof. Uhlmann to be present at the tutorial. We are happy that Margaret Cheney of RPI has agreed to speak.

Monday, January 30

Talks today are in the Seminar Room, Vincent Hall 570

9:00 am	**Registration and Coffee**	VinH 514 and IMA Lounge, VinH 502
9:30 am	**Welcome and Orientation**	Robert Gulliver
9:45 am	**William Symes** Rice Univ.	A Mathematical Overview of Reflection Seismology, I

Abstract: Reflection seismology produces very detailed information about the Earth's upper crust. It is the most widely used of all modern geophysical remote sensing techniques, particularly in the oil industry, and raises fascinating mathematical questions which have received only partially satisfactory answers. Most of the insight underlying the contemporary treatment of reflection seismic data is based on linearization and high-frequency asymptotics, which are used to analyze the relation between the coefficients of the wave equation (representing mechanical properties of the earth) and its solution (the seismic wavefield). The speaker will use these tools to provide a mathematical framework for understanding some of the basic concepts of reflection seismology, and will explore a few of the outstanding issues in the theory.

10:45 am	**Coffee Break** IMA Lounge, Vincent Hall 502	
11:15 am	**Jan Achenbach** Northwestern Univ.	Wave Analysis for Line-Focus Acoustic Microscopy, I

Abstract: The operation of an acoustic microscope will be briefly discussed. The instrument can be used in two modalities: imaging and measurements of wave speeds and attenuation. The quantitative mode of line-focus acoustic microscopy has proven to be a very useful technique for the determination of surface wave speeds and thereby the elastic constants, the thickness and even the mass density of an anisotropic thin film deposited on an anisotropic elastic substrate. The determination of these quantities is generally based on the measurement of the $V(z)$ curve, which is the record of the modulus of the measured voltage as a function of the distance z between the focus of the lens and the surface of the specimen. As discussed in these lectures, the velocities and the attenuation of modes of elastic wave propagation in a film/substrate configuration can be obtained from the

periodic variation and the decay of the $V(z)$ curve. To determine the mechanical constants, only brute force inverse methods have been successful. If the mass density is known, the elastic constants have been obtained by the use of an appropriate technique to best fit theoretical velocities obtained from a $V(z)$ measurement model to velocities obtained from the measured $V(z)$ curve. The procedure to determine the elastic constants of anisotropic films deposited on anisotropic substrates from $V(z)$ measurements obtained by the use of a line-focus acoustic microscope has three essential components: 1) the measurement of the $V(z)$ curve as a function of direction of wave mode propagation in the thin-film/substrate system at fixed frequency, and/or as a function of frequency or film thickness for a fixed direction, 2) the development of a theoretical measurement model for parametric studies of $V(z)$ curves, and 3) a procedure to obtain the elastic constants by systematic comparison of wave mode velocities obtained from the theoretical model and the $V(z)$ measurements. The examples concern primarily transition-metal nitride films and superlattice films that are used as hard protective coatings for softer surfaces. Results are presented for several thin-film/substrate configurations. The advantages of the method as well as remaining problems that require further investigation are discussed.

2:15 am	**Margaret Cheney** RPI	Inverse boundary value problems, I

Abstract: This series of talks will deal with inverse problems for certain elliptic and hyperbolic equations and with the connections between them. Techniques developed for hyperbolic inverse problems have yielded insight into elliptic ones; these talks will focus on the flow of ideas in the other direction.

The first three talks will deal with the elliptic impedance imaging problem, and will include a discussion of issues that arise in experimental verification of the theory. Images made from real data will be shown. The last talk will deal with a hyperbolic inverse scattering problem for wave propagation in a medium with variable sound speed.

4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Tuesday, January 31

9:45 am	**William Symes** Rice Univ.	A Mathematical Overview of Reflection Seismology, II
10:45 am	**Coffee Break** IMA Lounge, Vincent Hall 502	
11:15 am	**Jan Achenbach** Northwestern Univ.	Wave Analysis for Line-Focus Acoustic Microscopy, II
2:15 pm	**Christof Stork** Advance Geophysical Corp.	Practical issues of wavefield inversion in seismic oil exploration, I

Abstract: Current methods for transforming seismic data into subsurface images can be considered crude in light of today's mathematical understanding of wave propagation and inversion. These current methods are mainly effective for mapping geologic beds in areas of little complexity. This map contains little or no information about the properties of the geologic beds. A research objective of the seismic oil exploration community is to push seismic processing to produce more information in the simple structures and to be more reliable in complex structures. Wavefield inversion techniques have potential for achieving these objectives. However, the inherent limitations of the seismic experiment make the application of wavefield inversion techniques difficult. For example, attempts to use an iterative application of the Born scattering principle have essentially failed. Some basic models serve to demonstrate the problems caused by the inherent limitations of the seismic experiment. These models provide analysis of possible solutions to the problems.

Despite the inherent limitations of the seismic experiment, the use of wavefield inversion techniques should hold the potential for vastly improved subsurface images or, at least, incremental improvements over present crude methods. Why isn't some of this potential being realized and why isn't industry aggressively pursuing

wavefield inversion methods for seismic imaging? The answer is that one cannot currently produce and will probably never produce a "black box" for processing seismic data. The "black box" needs to be modified to incorporate application-specific controls and constraints. Methods for providing efficient user input to wavefield inversion methods in a manner understandable by a non-PhD level human are at an early stage of development. Furthermore, the graphical computer programming necessary to implement this control capability is a rather daunting task. However, these tasks are as critical to making use of all the information available in seismic data as the development of appropriate wavefield inversion methods. Constraints in reflection tomography serve as an example of the specification on a graphical workstation of constraints on the "black box".

SEMINAR IN { **Combinatorics** / **Vincent Hall 570** }

4:40 pm	**Dave Bressoud** Macalester College	Some additional observations on the Borwein conjectures

Abstract: Dennis Stanton talked about Peter Borwein's conjecture that certain families of polynomials have non-negative coefficients. One of the natural places to locate this conjecture is in the study of the generating functions for partitions with prescribed hook differences. We'll look at what can be said about the Borwein conjecture in this context.

Victor Reiner, Organizer

Wednesday, February 1

9:45 am	**William Symes** Rice Univ.	A Mathematical Overview of Reflection Seismology, III
10:45 am	**Coffee Break** IMA Lounge, Vincent Hall 502	
11:15 am	**Margaret Cheney** RPI	Inverse boundary value problems, II
2:15 pm	**Christof Stork** Advance Geophysical Corp.	Practical issues of wavefield inversion in seismic oil exploration, II

SEMINAR IN { **Mathematical Physics** / **Room Vincent Hall 206** }

3:30 pm	**S. Y. Wu** Columbia University	Symplectic Cutting and Geometric Quantization

Organizer: Peter Olver

Thursday, February 2

9:45 am	**William Symes** Rice Univ.	A Mathematical Overview of Reflection Seismology, IV
10:45 am	**Coffee Break** IMA Lounge, Vincent Hall 502	
11:15 am	**Margaret Cheney** RPI	Inverse boundary value problems, III

2:15 pm	**Christof Stork** Advance Geophysical Corp.	Practical issues of wavefield inversion in seismic oil exploration, III

Mathematics Colloquium, Room Vincent Hall 16

3:30 pm	**Blaise Morton** Honeywell Corporation	Structured Singular Values—Applications and Algebraic Theory
6:30 pm	**Workshop Dinner** Holiday Inn, Balcony	Wine and cheese will be served starting at 6:30 pm, dinner at 7:00

Friday, February 3

9:45 am	**Christof Stork** Advance Geophysical Corp.	Practical issues of wavefield inversion in seismic oil exploration, IV
10:45 am	**Coffee Break** IMA Lounge, Vincent Hall 502	
11:15 am	**Margaret Cheney** RPI	Inverse boundary value problems, IV

Monday, February 6

1:00-5:00 pm	**Indust. Postdoc Seminar**	Presentation of projects and problems from industry

IMA Industrial Postdocs Seminar

The seminar will meet from 1:00 pm – 5:00 pm today. The format of the seminar is:

1. Presentation of projects and problems from industry (Honeywell, Siemens, 3M and Unisys) on which the industrial postdocs are working.
2. Informal suggestions and discussion among the participants.

The seminar is directed by Avner Friedman and Walter Littman. Visitors who plan to attend are requested to inform Dr. Friedman.

SEMINAR IN $\left\{ \begin{array}{l} \textbf{Mathematical Physics} \\ \textbf{Room Vincent Hall 301} \end{array} \right.$

3:30 pm	**Graeme Milton** University of Utah Vin H 301	Variational Principles for the equation $\nabla \cdot f(x, \nabla u) = 0$ when there isn't an energy to minimize

Abstract: We consider the pde $\nabla \cdot f(x, \nabla u) = 0$, where f is some non-linear vector-valued or tensor-valued function, which is a monotone function of the second argument (although this restriction can be relaxed somewhat, using Null-Lagrangians) and u is a scalar or vector potential. For example the equation could represent equilibrium Cauchy elasticity in the absence of body forces. The variational principles use two trial fields, a trial potential and a trial current (stress) field. They are extensions of variational principles that Cherkaev and Gibiansky obtained in the linear case for viscoelasticity and complex conductivity, which have been successfully used to bound complex effective moduli of composites.

Organizer: Peter Olver

Tuesday, February 7

IMA Postdoc Seminar

2:30 pm **Paul Sacks** The phase problem in inverse scattering
Iowa State University

Abstract: We consider the one-dimensional inverse scattering problem of quantum mechanics, in which one seeks to determine a potential $V(x)$ in the Schrödinger equation from scattering data. In the standard approach to this problem it is assumed that $R(k)$, the complex-valued reflection coefficient, is known, but in many interesting applications only the magnitude $r(k) = |R(k)|$ can be measured. The phase problem in inverse scattering thus consists in recovering the potential $V(x)$ when the phase of $R(k)$ is not available. In general this missing information introduces a high degree of non-uniqueness into the problem, and one must compensate by using other kinds of information. For example one might restrict the class of admissible potentials in some way consistent with the physics of the situation, or one might assume that some other kind of data related to the usual scattering data is available. In this talk we will discuss uniqueness results and numerical reconstruction techniques for some specific problems of this type.

Organizer: S. Patch

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

SEMINAR IN { **Combinatorics**
Vincent Hall 570

4:40 pm **To be announced**

Victor Reiner, Organizer

Wednesday, February 8

SEMINAR IN { **Partial Differential Equations**
Vincent Hall 206

3:35 pm **Changmei Liu** A scattering theory analogue of a theorem of Polya and an inverse obstacle problem
IMA

Thursday, February 9

SEMINAR IN { **Numerical Analysis**
Vincent Hall 570

11:15 am **Shih-Hsien Yu** On pointwise estimates of a finite difference scheme for scalar conservation laws
Stanford/IMA

Mitch Luskin, Organizer

Friday, February 10

Monday, February 13

SEMINAR IN $\left\{ \begin{array}{l} \textbf{Mathematical Physics} \\ \textbf{VinH 570} \end{array} \right.$

3:30 pm **Mark Fels** University of Minnesota — Applications of the Equivalence Method to the Inverse Problem in the Calculus of Variations, I

Abstract: In this talk we will first discuss the invariant nature of the inverse problem of the calculus of variations (and some of its generalizations). In particular, the existence of variational principles for a differential equation are directly related to the existence of closed forms on the equation manifold defined by the differential equation(s).

The invariant nature of the problem suggests one should express conditions which determine if an equation admits variational principles in terms of the relative invariants which arise in the equivalence method. As an example we will look closely at fourth order scalar ordinary differential equations.

If time permits, we will discuss the role of exterior differential systems in generalizations of the inverse problem.

Organizer: Peter Olver

Tuesday, February 14

IMA Postdoc Seminar

2:30 pm **Changmei Liu** Rochester/IMA — Global Estimates for Solutions of Partial Differential Equations and Uniqueness for A General Class of Inverse Problems

Abstract: For polynomials $P(\xi)$ with constant complex coefficients which are **simply characteristic**, we prove that the operator defined by $R(z)f = \mathcal{F}^{-1}((P(\cdot) - z)^{-1}\hat{f})$, where $\wedge$ denotes the Fourier transform and $\mathcal{F}^{-1}$ denotes its inverse, is bounded from B_s to B^*_{1-s}, $0 \leq s \leq 1$. Furthermore, if $P(\xi)$ is elliptic and the principal part $P_m(\xi)$ is such that $\nabla_\xi(Re(P_m(\xi+\zeta)))$ and $\nabla_\xi(Im(P_m(\xi+\zeta)))$ are linearly independent on the zero set of $P_m(\xi+\zeta)$ for each complex vector $\zeta \in \mathbf{C}^n$ in the complex variety $M_\zeta = \{\zeta \in \mathbf{C}^n : P(\zeta) = 0\}$, then

$$||R(z,\zeta)f||_{B^*_{1-s}} = ||\mathcal{F}^{-1}((P(\cdot+\zeta) - z)^{-1}\hat{f})||_{B^*_{1-s}} \leq C_{s,P} \sup_{\xi \in \mathbf{R}^n} \frac{1}{\tilde{P}(\xi,\zeta)}||f||_{B_s}$$

with $C_{s,P}$ independent of ζ and $\sup_{\xi\in\mathbf{R}^n} \frac{1}{\tilde{P}(\xi,\zeta)} \to 0$ as $|\zeta| \to \infty$ in M_ζ. Finally, as an application, we prove that potentials q that are compactly supported can be uniquely determined by their scattering amplitudes at fixed non-L^2 eigenvalue $\lambda \in \mathbf{R}$ for a general class of differential operators.

Organizer: S. Patch

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

SEMINAR IN $\left\{ \begin{array}{l} \textbf{Combinatorics} \\ \textbf{Vincent Hall 570} \end{array} \right.$

4:40 pm **Scot Adams** Univ. of Minnesota — Hyperbolic groups and metric spaces in dynamics

Abstract: A geodesic metric space is *δ–hyperbolic* if every geodesic triangle has the property that each side is in the δ–neighborhood of the union of the other two. It is *hyperbolic* if it is δ–hyperbolic for some nonnegative δ. A finitely generated group is *hyperbolic* or *word hyperbolic* if, for any finite generating set, the geometric realization of its Cayley graph is a hyperbolic metric space. Remarkably, it seems to be true that, in a very specific sense,

almost every finitely generated group is word hyperbolic, so that results about such groups are to be thought of as results about the generic finitely generated group. On the other side of the spectrum, there are higher-rank semisimple Lie groups (and lattices therein), which are quite special. I will discuss a theorem whose philosophy is that word hyperbolic groups and higher-rank groups are utterly incompatible from the point of view of smooth and measurable dynamics. Much of the talk will focus on the geometry of Cayley graphs of hyperbolic groups, especially the boundary theory of such graphs.

Victor Reiner, Organizer

Wednesday, February 15

SEMINAR IN { **Partial Differential Equations** / **Vincent Hall 206** }

3:35 pm **George Sell** Global attractors for the 3D Navier-Stokes Equation
Univ. of Minnesota Vincent Hall 206

Thursday, February 16

SEMINAR IN { **Numerical Analysis** / **Vincent Hall 570** }

11:15 am **To be announced**

Mitch Luskin, Organizer

Friday, February 17

10:30 am **Coffee Break**
IMA Lounge, Vincent Hall 502

SEMINAR ON INDUSTRIAL PROBLEMS

11:15 am **Pu Sun** A Pseudo Non-time Splitting Scheme In Air Quality Modeling
Supercomputing Ctr. of N. Carolina

Abstract: A pseudo-non-time-splitting scheme, which combines advection and chemical reaction processes in the conventional time-splitting air quality modeling method into one step is introduced. In this new scheme, the term in the rate of change in the advection equation which has space derivative is computed as usual, and is then combined into the chemical reaction equation as a source term there. The other term which does not depend on the space derivative is directly combined into the chemical reaction equation and changes dynamically there. It is believed that by combining these processes together, the errors due to the time-splitting scheme may be reduced, and the physical process may be more accurately modeled, while the computational time remains almost the same. A cosine hill rotation with chemical reaction example is computed and the differences between the results of the new scheme and the conventional scheme are investigated.

The SEMINAR meets in Vincent Hall 570

Monday, February 20

11:15 am	**Guy Chavent** CEREMADE & INRIA	Geometric methods for the analysis of non-linear inverse problems, I

Abstract: Nonlinear inverse problems are usually solved in the least-square sense;

$$\text{(P)} \qquad \min_{x \in C} J(x) \overset{\Delta}{=} \frac{1}{2} \|z - \varphi(x)\|_F^2$$

where $C \subset E$ is the (usually convex) set of admissible parameters, $z \in F$ is the data, $\varphi : C \to F$ is the (usually regular) mapping to be inverted, and E, F are Hilbert spaces. Methods based on a compactness hypothesis for C or φ allow one to prove existence of solutions of (P), but give no insight on the uniqueness of the solution or the unimodality of the objective function J. These two questions are of great practical importance for the numerical resolution of (P) by local optimization techniques, as they ensure that the algorithm will converge to the global minimum instead of being stuck in some non-significant local minimum.

In this talk, we shall explain how the study of the geometrical properties of the output set $\varphi(C)$ (size, curvature, deflection) leads to sufficient conditions for the problem (P) to be quadratically well posed (existence, uniqueness of the solution, unimodality of J for all z in a neighborhood of $\varphi(C)$), and give examples of applications to the estimation of the coefficients in an elliptic equation from an H^1 measurement of its solutions.

This is the first of two talks.

SEMINAR IN $\left\{\begin{array}{l}\textbf{Mathematical Physics}\\ \textbf{VinH 570}\end{array}\right.$

3:30 pm	**Mark Fels** University of Minnesota	Applications of the Equivalence Method to the Inverse Problem in the Calculus of Variations, II

Abstract: See February 13 announcement.

Organizer: Peter Olver

Tuesday, February 21

11:15 am	**Guy Chavent** CEREMADE & INRIA	Geometric methods for the analysis of non-linear inverse problems, II

Abstract: "Real-life" nonlinear inverse problems are usually ill-posed, and hence do not satisfy the geometrical conditions which would ensure their quadratic-wellposedness! So it is a current usage to replace the solution of (P) by that of

$$(\mathrm{P}_{\varepsilon,\delta}) \qquad \min_{x \in C} J_{\varepsilon,\delta}(x) = \frac{1}{2} \|z_\delta - \varphi(x)\|_p^2 + \frac{\varepsilon^2}{2} \|x - x_0\|_E^2$$

where x_0 is an a-priori guess for x, $\varepsilon > 0$ is the regularization parameter, and z_δ is a "noisy" approximation to z. By analogy with the linear case, one would expect that the solution $\hat{x}_{\varepsilon,\delta}$ of $(\mathrm{P}_{\varepsilon,\delta})$ converges, where $\varepsilon, \delta \to 0$ adequately, to the x_0-minimum norm solution $(x_0 - MNS)$ of (P). In general however, there is no guarantee that, for small ε's, the problem $(\mathrm{P}_{\varepsilon,\delta})$ is quadratically well posed — in which case the regularized problem $(\mathrm{P}_{\varepsilon,\delta})$ is not solvable by local gradient techniques.

In this second talk, we shall show how the geometrical techniques introduced for the study of the unregularized problem (P) allow one to define a class of inverse problems, called "weakly non-linear", for which the regularized problem $(\mathrm{P}_{\varepsilon,\delta})$ is quadratically well posed for all small enough ε's (hence is numerically solvable) and enjoys all the nice properties of the linear case. We shall illustrate this on the estimation of the source term in a weakly nonlinear elliptic equation. Time permitting, we shall show, for strongly non-linear inverse problems, how a different kind of regularization, called the state-space regularization, allows one in certain circumstances to define once again a sequence of quadratically well-posed regularized problems. As an application, we shall consider the example of the first talk when only an L^2 measurement of the data is available.

IMA Postdoc Seminar

2:30 pm **Shih-Hsien Yu** Stanford/IMA — Convergence of the Lax-Wendroff Scheme for Piecewise Smooth Solutions with Shocks

Abstract: This paper concerns the convergence of Lax-Wendroff schemes to a piecewise-smooth solution for a scalar conservation law. We treat this numerical solution around a shock and in a smooth region differently. A concept of shock location for a numerical solution is developed to track an $O(1)$ error resulted from the shock. A suitable weighted L^2 norm around the shock and Lax's stability theorem for smooth solutions are applied to obtain a pointwise error estimate. It shows that the error of the shock location is $O(\Delta x)$ and that the oscillation associated to $O(1)$ error does not affect the accuracy the the scheme in the smooth region. Furthermore, it shows that this $O(1)$ error is located around the analytic shock and decays in space away from the shock with a rate proportional to $1/\Delta x$. It proves that the convergence rate is Δx for L^1-norm.

Organizer: S. Patch

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

SEMINAR IN { **Combinatorics** / **Vincent Hall 570** }

4:40 pm **To be announced** — To be announced

Victor Reiner, Organizer

Wednesday, February 22

11:15 am **Paul Sacks** Iowa State University — The Inverse Spectral Problem On a Finite Interval, I

Abstract: In the inverse spectral problem one seeks to recover a differential operator from information about its spectrum. It is of fundamental importance in the subject of inverse problems not only on account of its own intrinsic interest, but also because of the variety of mathematical techniques it has given rise to. In these lectures I will describe the principal formulations of the inverse spectral problem on a finite interval, and survey a number of different methods which have been developed to study them. Attention will also be paid to derivation of computational methods.

This is the first of two talks.

SEMINAR IN { **Partial Differential Equations** / **Vincent Hall 206** }

3:35 pm **Peter Perry** University of Kentucky — Inverse spectral theory for fourth-order ordinary differential equations

Thursday, February 23

SEMINAR IN { **Numerical Analysis** / **Vincent Hall 570** }

11:15 am **Dai-Gyoung Kim** IMA — Wavelet decompositions and their applications

Mitch Luskin, Organizer

2:30 pm **Paul Sacks** Iowa State University — The Inverse Spectral Problem On a Finite Interval, II

Mathematics Colloquium, Room Vincent Hall 16

3:30 pm **Satyanad Kichenassamy** University of Minnesota — Mathematical Problems in Computer Vision

Abstract: Computer vision deals with the processing of images, in order to retrieve and enhance information for human or automatic interpretation. Image processing concepts have been successfully applied in astronomy, biology, medicine, law enforcement, defense, and industry.

We illustrate the impact of modern mathematical tools on this subject by presenting a new algorithm for contour recognition, which we developed with A. Kumar, P. Olver, A. Tannenbaum and A. Yezzi. It is based on a curve shortening flow in a conformally flat two-dimensional space. It leads to the analysis of a non-linear, non-divergence parabolic equation, analyzed by the method of viscosity solutions.

The result of its numerical implementation will be discussed and compared with other recent algorithms.

Technicalities will be kept to a minimum. This talk should be accessible to all graduate students.

Friday, February 24

10:30 am **Coffee Break**
IMA Lounge, Vincent Hall 502

SEMINAR ON INDUSTRIAL PROBLEMS

11:15 am **John Hamilton** Eastman Kodak — Fluid flow in a porous medium

Abstract: We consider the absorption of fluid into a thin porous layer. The fluid starts out as a drop on top of the porous layer when it is dispensed by a syringe. The first part of the problem involves solving for the penetrating flow which has a moving frontier and an impervious bounding layer underneath. The second part involves tracking the concentration of materials within the porous layer as they move with the flow.

This is joint work with David Ross and Kam Ng.

The SEMINAR meets in Vincent Hall 570

SEMINAR IN { **Geometric Analysis** / **Vin H 206** }

3:35 pm **N. Conan Leung** Univ. of Minnesota — Introduction to the Seiberg-Witten equations

Monday, February 27

SEMINAR IN { **Mathematical Physics** / **VinH 570** }

3:30 pm **Gopala Srinivasan** University of Minnesota — To be anounced

Organizer: Peter Olver

Tuesday, February 28

11:15 am	**Rakesh** University of Delaware	Inverse Problems for the Wave Equation, I

Abstract: The Progressing Wave Expansion (a.k.a. Geometrical Optics) and Unique Continuation for the Wave Equation in Time-Like Directions are two tools which have helped prove uniqueness and continuous dependence for certain inverse problems for the wave equation. We introduce these tools and show how they have been used in inverse problems.

This will be the first of two, or possibly three, hour talks.

IMA Postdoc Seminar

2:30 pm	**Dai-Gyoung Kim** Purdue/IMA	Image compression through Wavelet transforms with boundary treatments

Abstract: Many researchers have developed wavelet bases on the unit interval. From a practical point of view, their constructions have some disadvantages. We introduce a different construction that avoids those disadvantages while preserving their advantages. As an application to image compression, we apply a certain compression algorithm to the wavelet transforms with boundary treatments. Also, we estimate empirically the smoothness of images in Besov spaces.

Organizer: S. Patch

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

SEMINAR IN $\left\{ \begin{array}{l} \textbf{Combinatorics} \\ \textbf{Vincent Hall 570} \end{array} \right.$

4:40 pm	**Vic Reiner** Univ. of Minnesota	Non-crossing partitions and their incidence algebra

Abstract: For some of our most-beloved partial orders (Boolean algebras, finite vector space lattices, products of chains, partition lattices) there is an isomorphism between their "reduced incidence algebras" and some simple power series ring, giving one explanation for why the answers to enumerative problems about these posets (typically chain-counting problems) have nice generating functions. Recently, Nica and Speicher gave such an isomorphism for the lattice of non-crossing partitions. The talk will review incidence algebras, and discuss Nica and Speicher's result. We will then use it to give a "quick" derivation of the zeta polynomial for the lattice of non-crossing partitions.

Victor Reiner, Organizer

Wednesday, March 1

11:15 am	**Rakesh** University of Delaware	Inverse Problems for the Wave Equation, II

Thursday, March 2

11:15 am	**Rakesh** University of Delaware	Inverse Problems for the Wave Equation, III
1:00-5:00 pm	**Indust. Postdoc Seminar**	Presentation of projects and problems from industry

IMA Industrial Postdocs Seminar

The seminar will meet from 1:00 pm – 5:00 pm today. The format of the seminar is:

1. Presentation of projects and problems from industry (Honeywell, Siemens, 3M and Unisys) on which the industrial postdocs are working.
2. Informal suggestions and discussion among the participants.

The seminar is directed by Avner Friedman and Walter Littman. Visitors who plan to attend are requested to inform Dr. Friedman.

Friday, March 3

SEMINAR ON INDUSTRIAL PROBLEMS

11:15 am	**Charles Wampler** General Motors	Robots, mechanisms and polynomial continuation

The SEMINAR meets in Vincent Hall 570

CURRENT IMA PARTICIPANTS

POSTDOCTORAL MEMBERS FOR 1994-95 PROGRAM YEAR

NAME	PREVIOUS/PRESENT INSTITUTION
Bronski, Jared C.	Princeton University
Jaksic, Vojkan	University of Kentucky
Kargol, Armin	VPI&SU
Kim, Dai-Gyoung	Purdue University
Liu, Changmei	University of Rochester
Luo, Erding	UCLA
Patch, Sarah	UC Berkeley
Yu, Shih-Hsien	Stanford University

POSTDOCTORAL MEMBERSHIPS IN INDUSTRIAL MATHEMATICS FOR 1994-95

NAME	PREVIOUS/PRESENT INSTITUTION
Cockburn, Juan C.	University of Minnesota
Copeland, Mark A.	Clemson University
Huntley, Douglas	Northwestern University
Kutz, Jose Nathan	Northwestern University
Nitsche, Monika	University of Colorado

CNRS POSTDOCTORAL MEMBER FOR 1994-95

NAME	PREVIOUS/PRESENT INSTITUTION
Ponenti, Pierre-Jean	Physique Théorique Marseille

VISITORS IN RESIDENCE (as of 11/29)

ACAR, ROBERT	Eastern Montana College	SEP 1 - AUG 31
ACHENBACH, JAN	Northwestern University	JAN 30 - FEB 3
AKTOSUN, TUNCAY	North Dakota State University	JAN 1 - MAR 31
BJORSTAD, PETTER E.	University of Bergen	FEB 17 - 19

BURRIDGE, ROBERT	Schlumberger-Doll Research Center	SEP 1 - MAR 31
CHAVENT, GUY	INRIA	JAN 3 - MAR 25
CHENEY, MARGARET	RPI	AUG 15 - JUN 15
CROC, ELISABETH	Universite de Provence (CNRS)	JAN 8 - MAR 31
CROW, JOHN	Cray Research	JAN 30 - FEB 3
CYBENKO, GEORGE	Dartmouth	FEB 17 - 19
DERMENJIAN, YVES	Universite de Provence	FEB 13 - MAR 18
DOBSON, DAVID	Texas A&M University	JAN 28 - FEB 3
FINCH, DAVID	Oregon State University	JAN 5 - MAR 31
FRIEDMAN, AVNER	IMA	
GULLIVER, ROBERT	IMA	
HAMILTON, JOHN	Eastman Kodak	FEB 23 - 24
HORN, MARY ANN	University of Minnesota	SEP 1 - AUG 31
KALNINS, ERNIE	University of Waikato	JAN 16 - FEB 3
KICHENASSAMY, SATYANAD	University of Minnesota	SEP 1 - JUN 30
LEE, CHOON-HO	Hoseo University (SNU)	DEC 20 - FEB 28
LEVINE, HOWARD	Iowa State University	FEB 7 - APR 7
LITTMAN, WALTER	University of Minnesota	SEP 1 - JUN 30
LUSKIN, MITCH	University of Minnesota	FEB 18 - 18
NI, WEI-MING	University of Minnesota	SEP 1 - JUN 30
PANIZZI, STEFANO	Universita di Parma	FEB 6 - JUN 30
PERRY, PETER A.	University of Kentucky	JAN 15 - MAR 30
RAKESH	University of Delaware	JAN 2 - MAR 31
REJTO, PETER	University of Minnesota	SEP 1 - JUN 30
SACKS, PAUL	Iowa State University	JAN 2 - MAR 31
SATTINGER, DAVID	University of Minnesota	SEP 1 - JUN 30
SCHREIBER, ROBERT	RIACS, NASA	FEB 17 - 19
SCOTT, RIDGWAY	University of Houston	FEB 17 - 19
SEO, SANGWON	Seoul National University	JAN 15 - FEB 15
SHAW, FRANK	Univ. of California-Riverside	JAN 1 - AUG 31
SOHN, WONKYU	Seoul National University	JAN 1 - MAR 31
STORK, CHRISTOF	Advance Geophysical Corporation	JAN 30 - FEB 3
SUN, PU	North Carolina Supercomputing Center	FEB 16 - 18
SVERAK, VLADIMIR	University of Minnesota	SEP 1 - JUN 30
SYMES, WILLIAM	Rice University	JAN 15 - FEB 3
WHITTINGTON, STUART	University of Toronto	FEB 4 - 6
ZIRILLI, FRANCESCO	Universita di Roma "La Sapienza"	SEP 1 - JUN 30

INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

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IMA NEWSLETTER # 225

March 5–31, 1995

1994-95 Program
WAVES AND SCATTERING

News and Notes

IMA Workshop:

Inverse Problems in Wave Propagation

March 6–17, 1995

Organizers: Jan Achenbach, Guy Chavent, George Papanicolaou, Paul Sacks, William Symes and Kennan T. Smith

Weekly IMA seminar list now available by list server

The IMA is happy to announce its new e-mail mailing list service. Currently we offer the mailing list "weekly" which is a distribution each Thursday of the next week's schedule of IMA seminars and events. If you wish to subscribe, simply send an e-mail message to `imalists@ima.umn.edu` whose first line is of the form

`subscribe weekly`

If your preferred e-mail address is different from the one from which you are sending the request, the first line should be

`subscribe weekly you@e.mail.address`

The subject line and the rest of the message are ignored. Questions or problems should be sent to `owner-weekly@ima.umn.edu`.

The current weekly schedule will still be available on request via `finger seminar@ima.umn.edu`. An updated `.dvi` file of the IMA Newsletter (current and recent) is also available by `ftp` or through the world-wide web.

Schedule for March 5–31, 1995

IMA Workshop:

Inverse Problems in Wave Propagation

March 6–17, 1995

Organizers: Jan Achenbach, Guy Chavent, George Papanicolaou, Paul Sacks, William Symes and Kennan T. Smith

Inverse problems in wave propagation originate in the notion that mechanical waves interact with material heterogeneities and propagate the information thus encoded over great distances. Therefore it should be possible to extract some information about distant heterogeneities from measurements of waves. Tasks of this nature arise in seismology, ocean acoustics/sonar, civil and environmental engineering, ultrasonic nondestructive testing, biomedical ultrasonic imaging, radar, and adaptive optics.

As might be expected from the range of applications, the subject is extremely heterogeneous. A wide variety of ideas and vocabulary characterize the literature.

In many applied fields, a signal processing viewpoint is commonplace: The data (wave measurements) are processed to obtain an image or other qualitative form of the target material heterogeneity. Another approach stays closer to the physics of wave propagation, and asks for a mechanical model which explains the data in detail. Tasks of this second fundamental type are the "inverse problems" of the title and form the subject of this workshop.

Since this subject involves many scientific and engineering disciplines, the jargon and intellectual habits of each field tend to obscure both common mathematical features and important differences. A primary goal of the workshop is to bring together inverse problem enthusiasts from a variety of disciplines, so that both similarities and distinctions become apparent. An example of a realized opportunity of this type is the correspondence between reflection seismology and nondestructive ultrasonic testing. It has become clear over the last decade or so that the so-called migration techniques developed by oil industry exploration seismologists are closely related to the Born approximation approach to inverse scattering employed by ultrasonics engineers in the 70's. The latter idea has provided a means to refine the information extracted from reflection seismograms, in work which is now being applied in industry.

Mathematicians have also studied a variety of inverse problems for hyperbolic partial differential equations, some only marginally related to applications. The classical questions of uniqueness, existence and continuous dependence demand for their resolution mathematical techniques which conceivably shed light on applications. As evidence one can cite the frequent occurence in the geophysical literature of phrases such as "ill-posed", "singular value decomposition", "Frechet derivative", etc. which are nowhere to be seen ten years ago. On the other hand, the demands of practical problems may suggest reformulations which would not be obvious from the viewpoint of contemporary mathematics, but which may in the end yield even better mathematical results.

The workshop will be focused on a number of open problems in the various areas and their mathematical underpinnings and associated computational issues:

- Approximation properties of linearization (of the data as function of the model, i.e. of the solution as function of the coefficients) with explicit attention to function spaces and norms;
- The velocity analysis problem in reflection seismology; and
- The use of waveform data in acoustic transmission experiments (as opposed to first-arrival tomography).

The topics of the workshop will be arranged in the following order:

1. NDE acoustic microscopy, material testing;

2. Inverse scattering and spectral problems;
3. Exploration geophysics;
4. Whole earth geophysics;
5. Medical imaging, computerized tomography;
6. Ground penetrating radar;
7. Ocean acoustics; and
8. Inverse problems in astronomy.

Monday, March 6

Talks today are in the Conference Hall, EE/CS 3-180

8:45 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:15 am	**Welcome and Orientation**	Avner Friedman, Robert Gulliver, William Symes
9:30 am	**James G. Berryman** Lawrence Livermore Nat. Labs	Variational Structure of Inverse Problems in Wave Propagation and Vibration

Abstract: Practical algorithms for solving realistic inverse problems may often be viewed as problems in nonlinear programming with the data serving as constraints. Such problems are most easily analyzed when it is possible to segment the solution space into regions that are feasible (satisfying all the known constraints) and infeasible (violating some of the constraints). Then, if the feasible set is convex or at least compact, the solution to the problem will normally lie on the boundary of the feasible set. A nonlinear program may seek the solution by systematically exploring the boundary while satisfying progressively more constraints. Examples of inverse problems in wave propagation (traveltime tomography) and vibration (modal analysis) will be presented to illustrate how the variational structure of these problems may be used to create nonlinear programs using implicit variational constraints.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00 am	**Kenneth P. Bube** Univ. of Washington	Convergence of Numerical Methods for Inverse Problems with General Input Sources

Abstract: The theory of a number of inverse problems requires that the input source be "impulsive" in time, i.e., it has an initial singularity like a delta-function or a jump discontinuity. In real data, this rarely is the case. The purpose of this study is to investigate the effect which the type of initial singularity in the source has on the convergence of numerical methods for inverse problems. We take as our test problem the one-dimensional inverse problem of reflection seismology. Using a standard second-order difference scheme to approximate the forward problem, we show that second-order convergence can be obtained in the inverse problem if either the source or its first derivative in time has an initial jump discontinuity. First-order convergence can be obtained if the second, third, or fourth derivative of the input source has an initial jump discontinuity. Surprisingly, first-order convergence can be obtained if any derivative of the input source has an initial jump discontinuity, provided the response is sampled and processed appropriately. We conclude that there is theoretically enough information in the sampled response to smooth input sources to solve the inverse problem to first order; numerically, the solution of the inverse problem may be very poorly conditioned. However, since the information is present in the response, regularized formulations for solving the inverse problem have a reasonable chance of success even with smooth input sources.

This is joint work with Robert Brookes.

2:00 pm	**Richard A. Albanese, MD** Armstrong Lab, Brook AFB	Wave propagation inverse problems of interest in medicine and environmental health

Abstract: Applications of wave propagation inverse methods to medicine and environmental health are discussed. The use of electromagnetic fields in non-invasive interrogation of living tissue to find diseased sites, including cancer, is addressed. The search for underground contamination is described as an analogous problem in environmental health.

Five inversion methods will be shortly outlined: frequency domain analysis, invariant imbedding, methods using far-field patterns and Herglotz kernels, stochastic wave equation technique, and Markov process methods. The applicability of each method will be suggested, and a view of future developments will be ventured.

Medical and environmental health needs for solutions to inverse problems involving propagating waves will be detailed. Wave propagation in tissue will be described with an emphasis on transient phenomena. Four biomedical events will be discussed: cellular adhesion and metastases, blood clotting, bone marrow interrogation, and bone repair. Electrocardiography and electroencephalography will be discussed if there is time. These biomedical events and measures will be related to wave propagation inverse problems.

SEMINAR IN $\left\{\begin{array}{l}\textbf{Mathematical Physics}\\ \textbf{Room Vincent Hall 570}\end{array}\right.$

3:30 pm	**Mikhail Foursov** University of Minnesota	The nonclassical conditional symmetries invariant and partially invariant under the classical Lie symmetries

Abstract: In this talk a new way of finding the nonclassical conditional symmetries of a PDE is explained. It was proved by E. Vorob'ev that the determining equations for nonclassical conditional symmetries inherit the classical symmetry group of the original equation. The other main idea behind the described method is the notion of invariant and partially invariant solutions to a partial differential equation (system of PDEs) under a classical symmetry group.

The method is illustrated on the example of the equation $u_{tt} = u\, u_{xx}$. This method is very useful in this case, since the system of determining equations for nonclassical conditional symmetries cannot be solved in any sort of generality. As a result, more than fifty invariant symmetries and fourteen partially invariant symmetries are obtained.

Organizer: Peter Olver

4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Tuesday, March 7

Talks today are in the Conference Hall, EE/CS 3-180

9:30 am	**K. J. Langenberg** University of Kassel, Germany	Applied inverse problems with acoustic, electromagnetic and elastic waves

Abstract: Computerized Tomography relies on the approximation of straight rays, and, insofar, it cannot be applied immediately to inverse wave propagation problems. Numerical simulations for acoustic waves clearly exhibit what kind of data should be processed in that case. Based on just a "look" at the data structure, heuristic imaging schemes like B-scan or SAR (Synthetic Aperture Radar) are readily formulated. Applying the algorithms to experimental data results in the requirement of an inverse scattering theory. Based on a Huygens-type formulation of backpropagation, a unified theory of linearized scalar inversion is discussed which contains, for example, SAR as a special case. A variety of examples are presented which either use experimental or synthetic data obtained from microwave remote sensing or ultrasonic nondestructive testing experiments.

As far as electromagnetic waves are concerned, polarization is an important feature and depolarization through scattering contains useful information to be utilized in inverse scattering. Therefore, applying dyadic algebra extensively, the above linear inverse scattering theory is extended to the polarimetric vector case. The application to synthetic data reveals the superiority of this new algorithm.

Elastic waves exhibit the phenomenon of mode conversion from pressure into shear waves and vice versa. It is evaluated how these effects can be incorporated into an elastodynamic inverse scattering theory, which, when applied to synthetic data, shows a definite improvement over existing algorithms neglecting mode conversion.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00 am	**Gen Nakamura** Josai University	Inverse problems in elasticity

Abstract: We will give an overview of recent developments concerning the inverse boundary problems for elasticity related to the Dirichlet-to-Neumann map. The Dirichlet-to-Neumann map is used for the identification of inhomogeneous elasticity tensors. We also mention about the related inverse problem using our approach.

1:30 pm	**Norman Bleistein** Colorado School of Mines	To be announced
2:40 pm	**Paul Sacks** Iowa State University	Inverse Scattering in Acoustic Media Using Transmission Eigenvalues

Abstract: Let $c(x)$ denote a velocity distribution in R^3 with $c(x) \equiv 1$ outside of some compact set. Let

$$u(x) = e^{ik(x\cdot\alpha)} + u_s(x) \quad \alpha \in R^3 \quad |\alpha| = 1$$

solve the corresponding Helmholtz equation

$$\Delta u + \frac{k^2}{c(x)^2} u = 0 \qquad x \in R^3$$

together with a suitable radiation condition. The far field pattern $F(\hat{x}, k, \alpha)$ corresponding to the given velocity c is defined by the asymptotic relationship

$$u_s(x) = \frac{e^{ikr}}{r} F(\hat{x}, k, \alpha) + O(\frac{1}{r^2}) \quad r = |x| \quad x = r\hat{x}$$

The inverse problem is to determine the inhomogeneity $c(x)$ from the far field pattern.

For the case that $c(x) = c(r)$, work of Colton–Monk and McLaughlin–Polyakov has shown that in some cases $c(r)$ is uniquely determined by a sequence of transmission eigenvalues which are associated to the sound speed, and which may be deduced from the far field pattern. In other cases the sound speed may be recovered from the transmission eigenvalues together with partial information about $c(r)$. In this talk I will discuss computational methods for recovery of $c(r)$ from this kind of data.

3:10 pm	**Sheryl M. Patrick** Univ. of Notre Dame	An Inverse Problem In Unsteady Aerodynamics And Aeroacoustics

Abstract: The feasibility of determining an unknown vortical disturbance in an approach flow to a streamlined solid body from the radiated sound is studied. The problem is treated in two separate parts. First, the inverse aerodynamic problem, wherein the upstream disturbance is determined from unsteady surface pressure, is considered. It is shown that the transverse component of an incoming vortical disturbance can be ***uniquely*** predicted from the surface unsteady pressure. This result can be extended for incoming turbulence in terms of the surface pressure density spectrum. The second problem treated is the inverse acoustic problem, wherein the

unsteady surface pressure is determined in terms of the radiated sound. It is shown that for a single frequency, the governing equation reduces to the Helmholtz equation, and in theory the solution to the inverse acoustic problem is *unique*. However, the problem remains ill-posed and regularization techniques must be applied to obtain solutions. The solution method chosen the singular value decomposition method with imbedded Tikhonov regularization. The results are quite reasonable but need to be tested with experimental data.

Joint work with Hafiz M. Atassi.

3:30 pm **Coffee Break**
Reception Room EE/CS 3-176

3:50 pm **Changmei Liu**
IMA/Univ. of Rochester
A Scattering Theory Analogue of A Theorem of Polya and An Inverse Obstacle Problem

Abstract: In the scattering of time-harmonic acoustic waves, whether an impenetrable ***sound-soft*** obstacle Ω can be completely determined by the scattering amplitude (or the far field pattern) $A_\Omega(\xi, k)$ given for $|\xi|^2 = |k|^2$ at fixed wave number $|k|$ and fixed incident plane wave direction k is still a question. In this paper, we show that at most finitely many distinct bounded Lipschitz domains can have the same scattering amplitude and a convex polyhedron in R^n $(n \geq 2)$ can be determined uniquely by its scattering amplitude. We also give a scattering-theory analogue of Polya's theorem.

4:20 pm **Michael Klibanov**
Univ. North Carolina, Charlotte
Diffusion Tomography: Novel Applications and Numerical Methods

Abstract: There is a recent interest in imaging of small inclusions hidden in the turbid media on the basis of light propagation. Lasers are used as light sources. Examples of turbid media are: biological tissues, murky water, foggy air, etc. Experiments show the differences in intensity profiles in media with and without inclusions. Therefore, there is a hope to image those abnormalities. Applications include an early breast cancer diagnosis, discovery of mine-like objects in the coastal water, etc.

Mathematically, this problem leads to a challenging n-dimensional(n=2,3) Inverse Scattering Problem either for diffusion or for telegraph equation. Recently, we (together with Prof. Semion Gutman) have developed and partially implemented several novel numerical methods for this ISP. These methods fall into two categories: (i) those with guaranteed global/local convergence, and (ii) those without rigorous convergence results. These algorithms will be presented together with numerical results. There is also a good chance that images obtained from real experimental data will be presented as well (the work on the latter is currently in progress).

Wednesday, March 8

Talks today are in the Conference Hall, EE/CS 3-180

9:30 am **John G. Harris**
Univ. of Illinois, Urbana
Modeling Scanned Acoustic Imaging of Defects at Solid Interfaces

Abstract: We construct explicit mathematical models both of a high-frequency, scanned acoustic microscope operating in a reflection mode, and of a low frequency, scanned confocal acoustic imaging system operating in a transmission mode. In both cases we examine how these devices image defects at interfaces and ask what quantitative information can be extracted from the image information. The acoustic microscope operates from 200 megahertz to several gigahertz. Accordingly, in modeling the acoustic microscope we are interested in describing the imaging of small surface-breaking cracks and in estimating their depth, where that depth may be only a few micrometers. This information can be used to characterize the initiation of fatigue damage in a solid. The confocal imaging system operates typically in a neighborhood of ten megahertz. In modeling this imaging system we are interested in understanding the degree of complexity captured by the acoustic image when the scatterers comprising solid-solid interfaces are at many length scales, most of which are less than a wavelength. This information is used to assess the quality and reliability of bonds between two solids. In both cases the focal region is mechanically scanned across the interface and the image is constructed point by point from the received

strength of the scattered focused sound. We explain, in some detail, how the sound scattered from defects in the focal region is mapped into the sound collected by the transducers and hence into the voltages they produce. It is important to recall that an acoustic transducer integrates all the sound collected by its aperture to produce a single voltage having both a magnitude and a phase. The models are approximate, make considerable use of reciprocity relations and depend upon asymptotic evaluations of Fourier integrals.

This is an expository summary of my and my collaborators' (Rebinsky, Yogeswaren and Wickham) recent work. Explicit models for the interfaces as well as the devices are constructed. The summary attempts to collect in one essay the general features shared by these imaging systems and to demonstrate the explicit features of their image formation mechanisms. The acoustic microscope has a very unique imaging mechanism. It excites, in addition to a reflected wave, a leaky Rayleigh wave at the surface being scanned. This wave is also collected by the transducer and is combined with the reflected wave to induce a voltage that is a sum of both waves. The surface wave enables the acoustic microscope to image the surface trace of a surface-breaking crack even though the trace is much less than a wavelength wide. Further, it enables the microscope to be used as an interferometer to measure the crack depth [1,2].The image formed by a scanned confocal pair of transducers, whose focal point lies on an interface, is not merely the outcome of reflection or transmission by an amplitude or phase object. When a focused beam strikes an interface having many compact scatterers, all at a wavelength or less in extent, multiple scattering among several of the scatterers occurs, because the focal region contains more than one scatterer. The image is therefore the outcome of a complex set of scattering events, rather than simple reflection or transmission. In fact the image may not accurately represent the structure of the interface [3,4],but instead may suggest that some other plausible interface structure is present.

References

[1] Rebinsky, D. A. and J. G. Harris. 1992. Proc. Roy. Soc. Lond. A 436: 254-265.

[2] Rebinsky, D. A. and J. G. Harris. 1992. Proc. Roy. Soc. Lond. A 438: 47-65.

[3] Yogeswaren, E. and J. G. Harris 1994. J. Acoust. Soc. Am. 96: 3581-3592.

[4] Harris, J. G., D. A. Rebinsky and G. R. Wickham 1995. Submitted for review.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00 am	**William Rundell** Texas A&M University	Determination of unknown coefficients from multiple input sources

Abstract: We consider the question of recovering coefficient(s) $c(x)$ from the equation $L(c)u_j = f_j(x)$ in a domain $\Omega \subset R^n$ subject to known Dirichlet data on the boundary $\partial\Omega$. The non-homogeneous source terms $\{f_j(x)\}_{j=1}^{\infty}$ form a basis for $L_2(\Omega)$. We will prove that in many cases of physical interest a unique determination is possible from data consisting of flux measurements g_j on $\partial\Omega$; that is, a single flux measurement for each input source. Algorithms that allow numerical approximation of the unknown coefficients from finite data will be given.

This is joint work with Bruce Lowe.

2:00 pm	**Andreas Ehinger** Inst. Francais du Petrole, Pau	Imaging complex geologic structures by the SMART method

Abstract: Imaging complex geologic structures is still an unresolved problem in the seismic industry. Although very considerable efforts have been spent in the last ten years or so, no overall satisfying method has been found even in the 2D case.

We have investigated an approach that is based on explicit use of traveltime information in a tomographic inversion process. The advantage of this approach is (at least) twofold: it is a global method in the sense that the found model simultaneously satisfies all traveltime information, and it allows straightforwardly the introduction of (e.g. geological) a priori information. The major shortcoming of reflection traveltime tomography is the

non-availability of input data. Indeed, seismic data from complex geologic structures is hardly interpretable: the wavefield undergoes very complex propagation and the wavefronts are perturbed in such a way that no spatially continuous reflections are recorded. To overcome this problem we propose a depth migration based method to access such traveltimes.

The combined use of reflection traveltime tomography and our special depth migration based access to traveltimes, the SMART method, comes down to just another implementation of migration velocity analysis. The methods summarized by this term aim at flattening events in migration coherency panels. However, most of these methods are based on local velocity update formulae restricted to simple geometries. Thus flattening may (or may not) be achieved iteratively. Using the SMART method we are sure to flatten events in just one iteration.

After the general presentation of our approach we address specific difficulties we are currently confronted with. These difficulties concern practical issues as well as theoretical ones and will be discussed in detail.

This is joint work with Patrick Lailly.

Thursday, March 9

Talks today are in the Conference Hall, EE/CS 3-180

9:30 am	**Doug Foster** Mobil Expl. & Prod. Tech. Ctr.	The Application of Elastic Wavefields In Exploration Geophysics

Abstract: In exploration seismology, inversion of reflection data for subsurface rock properties is the ultimate goal. Unfortunately, for a variety of reasons (i.e. bandlimited and erroneous data, finite aperture, etc.), this goal has not been realized. This does not mean that the inversion of reflection seismograms has not made an economic impact on the discovery of hydrocarbons. There is a form of inversion that has sucessfully found hydrocarbons in many basins throughout the earth. In the prospecting industry, this form of inversion is called amplitude versus offset (AVO) analysis. The basis of AVO analysis is the interpretation of a scattered-wave amplitude over a range of different angles (offsets). Historically, this analysis has not been quantitative but qualitative. Variations of reflections from hydrocarbon reservoirs have been used to find prospective areas. In this discussion, we provide a theoretical basis for an AVO inversion. This basis provides a means to quantitatively interpret the inversion of reflection seismograms. The underlying theory of this analysis is that in the absence of hydrocarbons, the three constituent rock properties (density, compressional and shear velocities) are correlated. They are not when hydrocarbons are present. This correlation has been observed over a range of different scales. High frequency (MHz) measurements of rock samples in the laboratory, midrange frequency (kHz) in situ measurements from well logs, and low frequency (Hz) measurements from seismograms exhibit this same property. This interpretational theory, appears to be robust in spite of several complicating circumstances (i.e. poor data quality, complicated lithologies, deep target zones, etc.). In addition, subtle changes in this correlation could be indicative of lithological variation as well.

This is joint work with Bob Keys and Denis Schmitt.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00 am	**Joyce McLaughlin** Rensselaer Polytech Inst.	Asymptotics for Standing Waves in Three Dimensions
1:30 pm	**Peter Annan** Sensors & Software Ltd	To be announced
2:30 pm	**Coffee Break** Reception Room EE/CS 3-176	

6:30 pm	**Workshop Dinner**	Campus Club, fourth floor of Coffman Union

This dinner will be an occasion to celebrate the recent eightieth birthday of Professor Boris Levitan. Workshop participants and friends and colleagues of Professor Levitan are encouraged to join us.

Wine and cheese will be served starting at 5:45 pm.

Friday, March 10

Talks today are in the Conference Hall, EE/CS 3-180

9:30 am	**Kurt J. Marfurt** Amoco Expl. & Prod. Tech. Group	Seismic Data Processing and Inversion, or, Codependency in the 90s

Abstract: If we define seismic inversion as estimation of geologic parameters from surface recorded seismic data, it would fall into 5 main categories:

1. seismic attribute analysis,
2. qualitative amplitude versus offset analysis (AVO),
3. quantitative AVO analysis,
4. target oriented full waveform inversion, and
5. 3D full waveform inversion.

Seismic attribute analysis, particularly the generation of 3D attribute volumes used in mapping trends, sweet spots, or pay zones is by far the most commonly used 'inverse' technique, though probably the one least familiar to this audience. Since the data volume is relatively small, careful, target specific 3D post stack or post migration processing can be easily achieved by the interpreter herself or through a small processing house that specializes in 'boutique' processing. When coupled via geostatistics to a priori geologic information in the form of well control, we obtain a simple yet quite robust geologically constrained seismic inversion 'algorithm'.

Analysis of 3D multiple offset data volumes via qualitative AVO analysis is the next most popular 'inversion' tool in our arsenal. Since the data volumes are on the order of tens of Terabytes, processing is almost always done using one of the half dozen large 3rd party geophysical contractors. The expense in achieving high quality 'true amplitude' information must be balanced with that of acquiring a larger survey providing denser coverage, greater aerial extent, more offsets, or more azimuths all within a fixed budget and within a fixed time frame.

Quantitative AVO analysis, typically performed on key lines, or along key target horizons, probably represents state-of-the-art inversion in the seismic industry. Here, we often process the data in-house, resorting to 'heroic processing' of most land and many marine data sets. Most quantitative AVO analyses involve some form of curve matching to synthetics generated from available or hypothetical well log control. This 'multiple hypothesis testing' approach to inversion avoids many of the nonuniqueness problems associated with full wave equation inversion. Obviously, the solution is only as good as the solution space investigated by the interpreter.

Target oriented full wave equation inversion is the $18/barrel version of the seismic inversion techniques that form the bulk of the presentations this week. Here, the parameterization is much more general, typically one of seismic impedances and velocities, allowing the data to more fully control the appearance of the geologic cross section. Both the quantitative AVO and full wave equation inversion techniques are highly sensitive to coherent noise, including surface waves and other guided waves, side scattered energy and both long and short period multiples.

Least square inversion techniques are routinely used in seismic data processing used to minimize this noise. Instead of inverting for a collection of seismic impedances in depth, we invert for 'moveout' curves in time. In the first situation we are inverting for the nonorthogonal 'diffraction coefficients' of non hyperbolic, time variant impulse responses, while in the later we are inverting for the 'transform coefficients' of typically nonorthogonal, time-invariant, linear, parabolic or hyperbolic curves. Both of these techniques—least-square impedance inversion and least-square transform inversion—suffer from nonuniqueness, with the nonuniquess of least square transform inversion commonly referred to as 'aliasing'. The effects of this nonuniqueness is most insidious when least-square processing to reject spatially aliased seismic noise. Fortunately, several non linear techniques, including inverse power weighting, alpha trim mean, and semblance weighting allow us to ameliorate this problem.

The challenges to full waveform inversion of surface seismic data include:

1. source and receiver coupling problems,
2. source wavelet problems,
3. transmission losses due to scattering and absorption,
4. mode converted energy 'loss',
5. 3D spreading and
6. structural complexity.

The first three problems are addressed by factoring these components out of the objective function. In quantitative AVO, the Symes et al. Discrete Semblance Operator (DSO) algorithm and the Chavent et al. Multiple Migration Fitting (MMF) algorithm, we attempt to match changes in amplitude and moveout with source location, receiver location and offset, rather than trying to obtain an absolute amplitude matches of a synthetic model to the data.

Quantitative AVO routinely accounts for (i.e. tries to fit!) energy loss due to mode conversion to shear waves. The DSO and MMF schemes have yet to include such first order changes in amplitude. The more rigorous fully elastic inversion schemes, such as those pioneered by the Tarantola or Carcionne teams currently require high fidelity multicomponent data.

At the end of this presentation I will present some work in progress aimed at correcting for 3D spreading and structural complexity, suitable for target-oriented inversion by either quantitative AVO or full waveform inversion techniques.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00 am	**Victor Isakov** Wichita State University	Uniqueness and stability of recovery of principal and diffusion coefficients for a second-order hyperbolic equation

Abstract: We study recovery of the leading coefficient (the speed of propagation) of a second-order hyperbolic equation from one special bounday measurement. This coefficient is assumed to be discontinuous and piecewise constant. The discontinuity surface is changing in time and space. We give sharp uniqueness results for this surface when additional measurements are implemented on an (arbitrarily) small part of the lateral boundary. We discuss possible reconstruction algorithms with one and many boundary measurements of the wave field generated by plane and spherical reference waves.

For the diffusion coefficient we give Hölder stability estimates of reconstruction in the case of several local boundary measurements.

2:00 pm	**Jeffrey J. Daniels** Ohio State University	To be announced

Monday, March 13

Talks today are in the Conference Hall, EE/CS 3-180

9:30 am	**Guust Nolet** Princeton University	Nonlinear inversion of seismic waveforms

Abstract: The path-integral (or WKBJ) approximation to the elastodynamic equations greatly reduces the number of model parameters in the waveform inversion problem, and enables us to partition the inverse problem into a small number of localized problems. It will be shown how we can combine the results of such local inversions into a large but linear inverse problem for 3D structure.

Items for discussion at the workshop include the definition of the objective function in the nonlinear optimization (which is not very objective after all), and possible inclusion of scattered waves using the Born approximation.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00 am	**Mikhail M. Lavrent'ev** Russian Acad. Sci. Siber. Br.	Methods to interpret astronomical data in view of Kozyrev's discovery

Abstract: A summary of the Kozyrev's discovery is presented in the report. The essence of this discovery is the existence of a previously unknown interaction between physical processes, the propagational velocity of this interaction exceeding many times the velocity of light. Experimental results are presented, obtained by a group of researchers from the Institute of mathematics (SD RAS, Novosibirsk), confirming the results by Kozyrev and revealing a number of new phenomena. Elements of the theory of interactions of this type are presented.

2:00 pm	**Allen Witten** University of Oklahoma	To be announced

SEMINAR IN { Mathematical Physics / Room Vincent Hall 570

3:30 pm	**Jeffrey Ondich** Carleton College	Partial invariance

Abstract: Lie's notion of group-invariant solutions of differential equations provides us with a tool for finding explicit solutions. L. V. Ovsiannikov generalized Lie's ideas to include "partially invariant" solutions, a natural geometric attempt to enlarge the class of solutions we can find for any particular system of PDEs. In this talk, I'll discuss the geometry of partial invariance, the algorithms for finding partially invariant solutions of PDEs, and the question of when it is worthwhile to look for partially invariant solutions.

Organizer: Peter Olver

4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Tuesday, March 14

Talks today are in the Conference Hall, EE/CS 3-180

9:30 am	**Philip B. Stark** Univ. of California	The need for wave equation travel-time tomography

Abstract: Within ray theory, travel times are sensitive to Earth structure on a set of zero measure. As a result, the uncertainties in tomographic images of Earth's interior based on ray theory are large, and extremely sensitive to smoothness assumptions that have little physical justification. Interpreting travel times as functionals of seismograms, incorporating more of the physics of wave propagation and the observation process, leads to "tubular tomography," in which travel times are sensitive to weighted volume integrals of the structure. The weights and the effective volume to which travel times are sensitive depend on the signal-to-noise ratio, as well as the source time function and instrument response function. The combined uncertainties in these parameters and functions makes it difficult to know what seismic travel times actually measure.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	

11:00 am	**Guy Chavent** CEREMADE & INRIA	Seismic waveform inversion via duality and progressive illumination

Abstract: Duality techniques and progressive illumination, by resolving the phase shift and destructive interference problems, provide a reformulation of the inversion problem solvable by local gradient methods. Duality and quantitative migration lead to a data-space defined reflectivity unknown, for which the data themselves provide a good guess. Plane wave illumination allows to increase the distance between illuminations along with the improvement of the background velocity unknown. Numerical results on 2-D synthetic data will be given.

1:30 pm	**Erik L. Ritman** Mayo Clinic	Local reconstruction applied to X-ray microtomography

Abstract: The essence of local reconstruction [1] is that the x-ray detector array need only be slightly wider than the projected diameter of the region of interest within the object. This feature of the local reconstruction method has several salutary practical consequences for tomographic imaging as follows:

A. The x-ray detector array can be smaller than the transverse diameter of the object being scanned. Consequently, commercially available arrays (that do not come in convenient sizes for global reconstruction, for which the entire transverse diameter of the object must be scanned) can be used. In micro CT applications this means that available charge coupled device (CCD) imaging arrays can be used in a minimally divergent xray beam [2]. In some applications the use of regular reconstruction algorithms [3], aided with "profile extension" based on knowledge of the object outside the imaging array, may be adequate. This is true if the composition of the nonscanned object is relatively homogeneous, such as an isolated heart specimen. Local reconstruction has the advantage that inhomogeneous structure is less of a problem and hence more broadly applicable, especially when bone or air is present within the sample to be scanned.

B. The smaller array also means that the x-ray can be collimated to just expose the array. This results in less x-ray exposure of the specimen (particularly important in living specimens) and, more important in terms of image quality, there is no image degradation due to x-ray scatter from the object outside the region of interest. This should result in better contrast within the imaged region of interest.

C. The smaller detector array also means that generally the imaged information does not contain the large range in image intensities that are inevitable when the entire transverse diameter (i.e., full thickness of object to surrounding air) is imaged. This means that greater x-ray intensity can be used (before the dynamic range of the detectors is exceeded), resulting in higher signal-to-noise ratio and/or that there is less demand for high dynamic range within the array detectors. This generally means that cheaper systems will meet the x-ray detection needs of the scanner.

D. The local reconstruction method we use also has a property similar to a high-pass filter, thereby enhancing edges of structures (with differing xray attenuation coefficient) within the region of interest. This is particularly important in imaging selectively opacified blood vessels because it facilitates measurement of vessel cross-sectional area, segment lengths and branching angles.

The local reconstruction method has several limitations that must also be recognized.

A. There is a trade-off between the energy (i.e., wavelength) of the xray photon and xray exposure that reduces the image contrast to be expected in a local reconstruction. Grodzins [4] pointed out that the smaller the diameter of the specimen scanned the lower should be the xray photon energy (and therefore the higher the attenuation coefficient) to achieve maximum contrast between different components of the specimen. Thus with local reconstruction the diameter of the specimen, not of the region of interest, is the operative dimension to be used in calculating the optimum xray photon energy. It follows that as the size of the specimen increases, relative to the local region to be reconstructed, we can expect the contrast between structures in the region-of-interest to decrease.

B. The local reconstruction loses the capability for the image grey scale to linearly convey the xray attenuation coefficient. Although this is acceptable when interfaces between structures are of primary interest, it may mean reduction of ability to identify and quantify material properties.

In summary, local reconstruction can enhance the capability of a micro-CT scanner beyond the limits set by the physical components and the use of global reconstruction.

This is joint work with John H. Dunsmuir, Adel Faridani, Paul J. Thomas and Kennan T. Smith.

References

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[2] Flannery B. P., H. W. Deckman, W. G. Roberge, K. L. D'Amico: Three-dimensional x-ray microtomography. Science 237:1439-1444, (Sept. 18) 1987.

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2:40 pm	**V. Tcheverda** Computing Center, Novosibirsk	The r-solution and its applications in inverse problems of wave propagation theory

Abstract: The r-solution for a compact operator in a Hilbert space is the generalized normal solution for an equation with finite–dimensional operator being a restriction of the initial operator onto the span of its r largest singular vectors. The main features of this notion are its stability and existence of numerical algorithms for its reliable computing ([1]). In the application to inverse problems of wave propagation, the r-solution appears when one attracts Newton–Kantorovich technique to solve the non-linear operator equation $A(c) = u_0$, where c is a wave velocity to be recovered by the data u_0. As a rule, the Fréchet derivative of the non-linear operator A is (if it exists) a compact operator and has no continuous inverse, while its r-pseudoinverse exists forever and is continuous and stable with respect to a perturbation of the initial operator.

The choice of the parameter r depends on the structure of the problem (distribution of singular values, accuracy of approximation, level of noise in the data, etc.) and on software and hardware used for the numerical solution. In accordance with preliminary computations there exists a close relation between the r-solution and separation of a medium into a "reflector" and a "propagator" ([2]).

Results of a range of numerical experiments of a recovering of a local lateral inhomogeneity located within vertically-inhomogeneous background are presented and discussed.

Joint work with V. Khaidukov and V. Kostin.

References

[1]Kostin V.I., Tcheverda V.A, 1995 *r-pseudoinverses for compact operators in Hilbert Spaces: existence and stability.* Submitted to J. of Ill-Posed and Inverse Problems.

[2]Chavent G., Clement F. Waveform inversion through MBTT formulation//Rapport de recherche n. 1839, janvier 1993, 38 p., INRIA (Domaine de Voluceau–Rocquencourt–B.P. 105–78153 Le Chesnay Cedex France).

3:10 pm	**Vassilis Papanicolaou** Wichita State University	Eigenvalue Asymptotics of Layered Media and Oceanographic Inverse Problems

Abstract: We compute the asymptotics of the eigenvalues of the Sturm-Liouville problem with a piecewise smooth coefficient q. This means that q and/or its derivatives can have jump discontinuities. The boundary conditions are arbitrary. Our work extends the classical asymptotic formulas for smooth q (obtained by Borg and Hochstadt). We also discuss applications of our results to inverse problem questions related to wave propagation in a layered medium, since the index of refraction of such a medium can be considered piecewise smooth.

This is joint work with Prof. G. Athanassoulis.

3:30 pm	**Coffee Break** Reception Room EE/CS 3-176	
3:50 pm	**V. G. Yakhno** Inst. of Mathematics, Novosibirsk	Multidimensional Inverse Problems in "Ray Formulations" For Some Hyperbolic Equations And Systems

Abstract: This talk deals with the Cauchy problems for acoustical equations, systems of equations for electrodynamics and elasticity. The right-hand sides of these equation and systems are generalized functions (vector-functions) describing impulsed point sources of acoustical, electromagnetic or elastic waves respectively. The first part of this talk is devoted to the description of the structures and properties of the generalized solutions of the Cauchy problems for the considered equations and systems. These properties of the generalized solutions are described in the forms which are necessary for further consideration of some inverse problems. The second part deals with multidimensional inverse problems "in ray formulation" and the results of its investigations. These problems consist in finding of the coefficients of the considered equations and systems as functions depending on the space variables. It supposes that the coefficients are smooth functions and have some constant values outside a limited domain. Moreover the coefficients appearing in the main parts of these equations and systems determine some Riemannian metrics, and the set of rays of these Riemannian metrics are supposed to be regular. From the physical point of view the coefficients of these equations and systems are unknown characteristics of inhomogeneous media in which the wave processes spread. The additional information for inverse-problem solving is the following. The dynamic wave fields are observed at the points of the boundary of considering domain in time interval of arriving the wave fronts from sources which are concentrated on the boundary of this domain. It shows that solving of this problems may be reduced to successive solving of inverse kinematic problems, tomography problems and others. From the mathematical point of view the main results of the investigation consist in uniqueness, stability theorems and for some special inverse problems the existence theorems also. These research results continue the investigation of the inverse problems which are described in the two monographs [1] and [2].

References

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4:20 pm	**Steven Cox** Rice University	On the Design and Identification of Dissipative Strings

Abstract: We analyze the spectra of the infinitesimal generators associated with both the interior and the boundary damping of strings. We state conditions on the distribution of damping and mass sufficient to (i) equate the decay rate with the spectral abscissa of the generator and (ii) render the map from damping to spectrum one-to-one. We present the results of an algorithm that recovers the damping from finitely many eigenvalues. We establish the existence of minimizers of the spectral abscissa. We present an analytical characterization of a local minimizer and present numerical evidence that it in fact provides a global minimum.

Wednesday, March 15

Talks today are in the Conference Hall, EE/CS 3-180

9:30 am	**Frank P. Pijpers** Uppsala Observatory, Sweden	Inversions in astronomy and the SOLA method

Abstract: In this talk a brief overview of applications of inversions within astronomy will be presented. Also an inventory of the techniques commonly in use will be presented. In general inversions in astronomy arise when observational (experimental) data are a convolution of some quantity of astrophysical interest and a known or measured instrumental effect. Since this data is sampled discretely and suffers from measurement errors of various kinds, it is rare that an exact analytical inversion can be carried out. Furthermore what distinguishes

astronomy from most other experimental physical sciences is that both the sampling and the data errors are difficult or impossible to control. A number of numerical inversion techniques are currently in use that try to deal with these difficulties in various ways. The talk is focussed on a small selection of astronomical inversion problems, where the method of Subtractive Optimally Localized Averages (SOLA) has been used. The SOLA method is an adaptation of the Backus & Gilbert method (1967, 1968, 1970). It was originally developed for application in helioseismology (Pijpers & Thompson, 1992, 1994) where the Backus & Gilbert method is too slow. Apart from achieving a considerable speedup in the SOLA formulation, the strength of the method lies in that it provides a good a priori estimate of the error due to data error propagation and similarly a good a priori estimate of the achievable resolution. The latter property in particular turns out to be of importance in the problem of reverberation mapping of active galactic nuclei (Pijpers & Wanders, 1994).

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10:30 am **Coffee Break**
Reception Room EE/CS 3-176

11:00 am **John Sylvester** Layer Stripping and the 1D Helmholtz Equation
University of Washington

Abstract: We shall discuss some new results concerned with one-dimensional inverse scattering (on the half line) for the Helmholtz equation. The linear version of the scattering/ inverse scattering transform (i.e the map from index of refraction to reflection coefficient) is the Born approximation, which, when calculated in travel-time variables, turns out to be the Fourier Transform. We shall show that two very basic theorems about the Fourier Transform, the Plancherel Equality and the Paley-Wiener Theorem, have nonlinear analogs for the scattering transform.

These theorems are part of the development of a mathematically rigorous and stable layer stripping algorithm for the Helmholtz equation. If time permits we will also discuss the application of this approach to the layered impedance tomography problem and speculate on the situation in dimension greater than one.

2:00 pm **Jeffrey R. Resnick** A comparison of imaging in medical ultrasound and exploration geophysics
Acuson

Abstract: Medical ultrasonic imaging is used by physicians to help diagnose disease in the human body. Seismic imaging is employed by geologists to aid in the search for hydrocarbons several miles beneath the earth's surface. Physicians and geologists speak in different vocabularies, and the objects that they image differ in scale by at least five orders of magnitude. Moreover, medical ultrasonic imaging systems display images in real time as the patient is scanned, while the results of seismic data processing usually postdate data collection by weeks or months. Despite these differences, medical ultrasound and exploration geophysics share much in common.

In this talk, I compare the imaging technologies of diagnostic ultrasound and geophysical exploration. Discussion centers on the following topics:

- wave propagation in human tissue and sedimentary rocks;
- geometry ofultrasonic transducers and seismic sources and receivers;
- source spectra, wavelet shaping, and deconvolution;
- ultrasonic beamforming and seismic migration and inversion;

- image display; and
- imaging objectives.

A comparison of ultrasonic and seismic imaging does not necessarily result in algorithms that can be directly or immediately ported from one technology to the other. It does, however, illuminate each from a new perspective, and suggests new directions for inquiry in both fields.

Thursday, March 16

Talks today are in the Conference Hall, EE/CS 3-180

9:30 am	**Robert L. Nowack** Purdue University	Applications of Inverse Methods to the Analysis of Refraction and Wide-Angle Seismic Data

Abstract: The inversion of seismic refraction data goes back to the work of Herglotz and Wiechert and the kinematic inversion for radially varying media. To illustrate inversions for 1-D structure, an inversion of observed upper mantle refraction data from a common receiver gather is presented. Non-uniqueness results from the occurrence of an upper mantle low velocity zone. In laterally varying media, kinematic linearizations of the time field are often used to invert for structure. Ray bending is usually incorporated by iteration of the linearized solution. Alternatively, recent higher order travel-time perturbation strategies can be utilized to avoid multiple ray traces. Constraints, such as damping and smoothing, reduce the non-uniqueness of the results. Kinematic inversions for laterally varying structure are illustrated using crustal and ultra-shallow seismic data. In order to incorporate more of the data, inversion of the seismic wavefield data can be performed. Without prior velocity analysis, however, this can be highly nonlinear. As an alternative, various seismic attributes, such as instantaneous frequency, envelope amplitude and phase time, can be extracted from the wavefield data and then inverted jointly or individually . Ray perturbation methods are utilized to obtain model sensitivity for these attributes. An inversion of seismic attributes using observed crustal refraction data is presented.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	

11:00 am	**Keith Kastella** UNISYS Corp.	A Fast Algorithm for Impedance Tomography

Abstract: Impedance tomography is used to image conductivity variations in the interior of objects. In analogy to X-ray tomography, several patterns of current are typically injected at the object+s surface and surface voltages are measured. Green's function, multi-grid, algebraic or layer-stripping methods can be used to invert this collection of surface measurements to construct the conductivity image. This talk will describe an FFT-based solution to the linearized problem. For the particular geometry studied here, the complexity of the algorithm is logarithmic in the number of volume elements and linear in the number of current projections.

1:30 pm	**Steven A. Johnson** University of Utah	Progress in applied inverse scattering for ground-penetrating radar, sonar, and medical ultrasound

Abstract: This one-hour talk reports progress in applying inverse scattering theory to imaging problems found in the fields of ground penetrating radar (GPR), sonar and medical ultrasound. This work is based on a common theme of modeling scattering processes using volume integral equations of the generalized Lippmann-Schwinger type. These integral equations are used for modeling both the forward problem and the scattering to remote detectors. Vector formulations are used for modeling electromagnetic and elastic wave propagation. Forward solutions computed using this approach compare closely with known analytic solutions such as scattering from coaxially layered cylinders. The inhomogeneous distribution of material scattering parameters is reconstructed by the process of *minimizing* the L^2 norm of the difference between the predicted and the measured scattered fields. The inversion code is amenable to course-grained parallelization and has been run with high efficiency

on a cluster of eight workstations. This method is being investigated as an improved method for breast cancer detection. In this case, high spatial resolution, accurate quantitative images of the speed of sound and absorption coefficient of test object and tissue, made using transmission data, are shown as progress toward eventual clinical applications. In most GPR and sonar applications, transmission data is not available and it is thus necessary to use reflection data of wide temporal bandwidth. Furthermore, the objects or targets to be imaged are located in media with infinite extent in several directions. This contributes to an increase in the computational complexity of the problem. We have found that use of layered Green's functions can both improve the conditioning of the problem and decrease the computational requirements. Examples of imaging buried objects in layered media are shown. Reconstructed images of the speed of sound of objects buried in ocean bottom sediment using simulated sonar data are show'n. Images of the permittivity of objects buried in sand made using broad band 1 GHz to 12 GHz data are also shown.

This is joint work with David T. Borup, Michael J. Berggren, Richard Eidens and James Wiskin.

2:30 pm	**Coffee Break** Reception Room EE/CS 3-176	
6:30 pm	**Workshop Dinner**	Holiday Inn, Balcony

Wine and cheese will be served on the Balcony (enter through bar off lobby) starting at 6:30 pm; dinner in the Avalon Room (third floor) at 7:00 pm.

Friday, March 17

Talks today are in the Conference Hall, EE/CS 3-180

9:30 am	**Michael D. Collins** Naval Research Lab, Washington	Inverse Problems in Ocean Acoustics

Abstract: There are many interesting inverse problems in ocean acoustics. These problems fall into two main categories, remote sensing and source localization. Among the environmental parameters that are of interest are the sound speed in the ocean, properties of sediments, topography of the seafloor, bubble distribution near the surface, and roughness of ice cover. Among the source parameters that are of interest are bearing, location, signature, path, and composition. For some problems, it is necessary to consider both environmental and source parameters simultaneously. Since most problems of interest are nonseparable and involve very large domains, the development of efficient techniques for solving the forward problem is very important. This paper will describe several inverse problems in ocean acoustics and some of the techniques in experimentation, forward modeling, and optimization that have been used to solve them.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	

The following talk is joint with the IMA Seminar on Industrial Problems

11:00 am	**Leonard Borucki** Motorola Adv. Custom Tech.	Failures Times in Metal Lines: Why a Lognormal Distribution?

Abstract: Metal lines of the kind that are commonly used in the semiconductor industry sometimes fail due to the migration of metal atoms under the influence of electric current and elevated temperatures. Under conditions of very high stress, failure times are almost always observed to be approximately lognormally distributed. This usually forms the basis for extrapolating failure times from stress conditions to normal operating conditions, but it is not really known whether the extrapolation is accurate.

Several theories have been advanced for the reasons underlying this almost universally observed failure distribution. One idea is that statistical differences in point defect diffusivities in grain boundaries within the metal lead to the pattern. However, recent experimental work on bicrystal metal lines containing grain boundaries with identical diffusivities also fail with a lognormal distribution. Thus, grain boundary transport statistics are not the sole explanation.

This talk will explore the question of whether the observed failure pattern offers any clues about the nature of the underlying transport processes that lead to failure, in particular whether there are any simple shared features are sufficient to explain what is happening.

2:00 pm	**G. H. Loechelt** Arizona State University	Characterizing Stress in Semiconductors Using Polarized Off-Axis Raman Spectroscopy

Abstract: The Raman effect has proven to be a very effective means of studying the vibrational properties of crystals. Starting in the early 1970s, researchers began to investigate the effects that lattice strain has on the Raman spectrum of silicon. They demonstrated the feasibility of detecting various forms of stress by means of Raman spectroscopy, which paved the way for developing this technique into a characterization tool. The last decade has seen the application of this concept on a microscopic scale for the purpose of stress mapping semiconductor devices. Using this technique, a variety of structures which are of interest to the semiconductor manufacturing community have been investigated.

Despite the success of this method, many ambiguities still remain. In particular, the conventional implementation of Raman spectroscopy fails to resolve the tensor nature of the stress. Instead, the quantity that is obtained represents a weighted average of stress components which can be interpreted in a variety of ways depending upon the nature of the stress. This inherent ambiguity limits the effectiveness of Raman spectroscopy as a truly quantitative characterization tool. The reason for this failure is that this technique uses a back-scattering geometry which can typically detect only one of three optical phonon modes present in the crystal. This one phonon mode contains partial information about the stress. To obtain full tensor information, one must be able to detect all three phonon modes.

A new technique called polarized off-axis Raman spectroscopy has been developed to overcome this limitation. By combining incident light tilted away from the normal axis with polarization of the incident and scattered light, any optical phonon mode can be selectively studied, thereby paving the way for characterizing the complete tensor nature of stress in semiconductors.

The fundamentals of this new technique will be discussed along with both computer simulations and experimental results. In particular, polarized off-axis Raman spectroscopy presents an interesting inverse problem, mathematically. One can readily calculate the Raman spectrum if the stress is known, since the Raman frequency is related to the eigenvalues and the signal intensities are related to the eigenvectors of a matrix whose coefficients depend linearly upon the components of the stress tensor. However, if given spectral information, how can one determine the stress tensor? Issues such as optimal experimental design and error estimation will also be addressed.

Joint work with N. G. Cave and J. Meñéndez.

Monday, March 20

IMA Special Lecture

2:30 pm	**M. M. Lavrent'ev** Russian Acad. Science, Siberian Br.	New methods to interpret the tomographical data

Abstract: Tomography is a scientific and technological lead that is intensively developing in the recent years. At present tomography is most widely employed in medicine. Many tomographical methods are applied in industry for quality control and in geophysics. Industrial and geophysical tomography have a number of distinctions as compared with the medical applications, and require new mathematical methods to be developed. A number of such methods will be presented in the report.

Tuesday, March 21

IMA Postdoc Seminar

2:30 pm	**Victor Isakov** Wichita State University	Stability of soft obstacles in inverse scattering

Abstract: We are interested in identification of a (bounded smooth) domain D in the three-dimensional euclidean space given its scattering amplitude (far-field) pattern $A(\sigma, x_i k)$ which is a coefficient of the first term of expansion (in powers of $1/r$) of a solution u of the Helmholtz equation (at frequency k) outside D which is zero on the boundary of D and behaves like $\exp^{(ik<x_i,x>)}$ at infinity. Here x_i is an unit vector (incident direction) and σ is the direction of x while r is $|x|$. We give estimates of the (Hausdorff) distance between two obstacles D given maximum norm of the difference of their scattering patterns for some fixed x_i and for a finite number of frequencies k which is determined by size of D. These estimates are of logarithmic type for smooth D and of almost Hölder type for analytic D. We discuss basic steps of proofs based o n sharp estimates of the continuation of solutions of elliptic equations and outline possible generalizations, improvements and open problems.

Organizer: S. Patch

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

SEMINAR IN { **Combinatorics** / **Vincent Hall 570** }

4:40 pm	**To be announced**	To be announced

Victor Reiner, Organizer

Wednesday, March 22

Thursday, March 23

Friday, March 24

University Holiday. IMA Offices will be closed.

Monday, March 27

Tuesday, March 28

Wednesday, March 29

Thursday, March 30

SEMINAR IN { **Numerical Analysis** / **Vincent Hall 570** }

11:15 am **To be announced**

Mitch Luskin, Organizer

Friday, March 31

SEMINAR ON INDUSTRIAL PROBLEMS

11:15 am	**David Freier** 3M Corp.	To be announced

The SEMINAR meets in Vincent Hall 570

CURRENT IMA PARTICIPANTS

POSTDOCTORAL MEMBERS FOR 1994-95 PROGRAM YEAR

NAME	PREVIOUS/PRESENT INSTITUTION
Bronski, Jared C.	Princeton University
Jaksic, Vojkan	University of Kentucky
Kargol, Armin	VPI&SU
Kim, Dai-Gyoung	Purdue University
Liu, Changmei	University of Rochester
Luo, Erding	UCLA
Patch, Sarah	UC Berkeley
Yu, Shih-Hsien	Stanford University

POSTDOCTORAL MEMBERSHIPS IN INDUSTRIAL MATHEMATICS FOR 1994-95

NAME	PREVIOUS/PRESENT INSTITUTION
Cockburn, Juan C.	University of Minnesota
Copeland, Mark A.	Clemson University
Huntley, Douglas	Northwestern University
Kutz, Jose Nathan	Northwestern University
Nitsche, Monika	University of Colorado

CNRS POSTDOCTORAL MEMBER FOR 1994-95

NAME	PREVIOUS/PRESENT INSTITUTION
Ponenti, Pierre-Jean	Physique Théorique Marseille

VISITORS IN RESIDENCE (as of 2/8)

ACAR, ROBERT	Eastern Montana College	SEP 1 - AUG 31
AKTOSUN, TUNCAY	North Dakota State University	JAN 1 - MAR 31
ALBANESE MD, RICHARD	Armstrong Lab, Brook AFB	MAR 5 - 17
ALESSANDRINI, GIOVANNI	Universita di Trieste	MAR 5 - 17
ANGELL, THOMAS S.	University of Delaware	MAR 13 - 17
ANNAN, PETER	Sensors & Software Ltd	MAR 5 - 17
BAO, GANG	University of Florida	MAR 1 - 31
BEISSEL, STEPHEN R.	Alliant Techsystems	MAR 24 - 24
BERENSTEIN, CARLOS	University of Maryland	MAR 5 - 17
BERRYMAN, JAMES G.	Lawrence Livermore National Laboratory	MAR 4 - 17
BEYLKIN, GREGORY	University of Colorado	MAR 7 - 13
BLEISTEIN, NORM	Colorado School of Mines	MAR 6 - 17
BORUCKI, LEONARD	Motorola Inc.	MAR 16 - 17
BRYAN, KURT M.	Rose-Hulman Institute of Technology	MAR 11 - 15
BUBE, KENNETH P.	University of Washington	MAR 5 - 17
BURRIDGE, ROBERT	Schlumberger-Doll Research Center	SEP 1 - MAR 31
CHAPMAN, CHRIS H.	Schlumberger-Cambridge Research	MAR 5 - 17
CHAVENT, GUY	INRIA	JAN 3 - MAR 25
CHENEY, MARGARET	RPI	AUG 15 - JUN 15
CHEVERDA, VLADIMIR	Russian Acad. Sci., Siberian Div.	MAR 5 - 17
COLLINS, MICHAEL D.	Naval Research Laboratory	MAR 5 - 17

COLTON, DAVID L.	University of Delaware	MAR 5 - 12
CROC, ELISABETH	Universite de Provence (CNRS)	JAN 8 - MAR 31
DANIELS, JEFFREY J.	Ohio State University	MAR 5 - 17
DASSIOS, GEORGE	University of Patras	MAR 5 - 17
DE HOOP, MARTIJN	Schlumberger-Cambridge Research	MAR 5 - 17
DELIC, GEORGE	Martin Marietta Technical Services, Inc.	MAR 12 - 17
DERMENJIAN, YVES	Universite de Provence	FEB 15 - MAR 31
DEVANEY, ANTHONY	Northeastern University	MAR 12 - 19
DOBSON, DAVID	Texas A&M University	MAR 5 - 17
EHINGER, ANDREAS	Institut Francais du Petrole, Pau	MAR 5 - 18
ERBE, CLAUDIA	University of Delaware	MAR 5 - 12
ESKIN, GREGORY	U. of California-Los Angeles	MAR 5 - 12
FARIDANI, ADEL	Oregon State University	MAR 5 - 17
FINCH, DAVID	Oregon State University	JAN 5 - MAR 31
FOSTER, DOUGLAS	Mobil Exploration & Producing Tech. Ctr.	MAR 5 - 17
FREIER, DAVID	3M	MAR 30 - 31
FRIEDMAN, AVNER	IMA	
GLADWELL, GRAHAM M.L.	University Waterloo	MAR 4 - 10
GUES, OLIVIER	Univ. de Rennes 1	MAR 15 - APR 15
GULLIVER, ROBERT	IMA	
HARIHARAN, S.I.	University of Akron	MAR 5 - 17
HARRIS, JOHN G.	U. of Illinois-Urbana	MAR 5 - 17
HORN, MARY ANN	University of Minnesota	SEP 1 - AUG 31
ISAACSON, DAVID	RPI	MAR 1 - 31
ISAKOV, VICTOR	Wichita State University	MAR 9 - 26
JOHNSON, STEVEN A.	University of Utah	MAR 5 - 17
KAUP, PETER	University of Delaware	MAR 5 - 17
KEINERT, FRITZ	Iowa State University	MAR 13 - 17
KEYS, ROBERT	Mobil Oil Corporation	MAR 5 - 17
KICHENASSAMY, SATYANAD	University of Minnesota	SEP 1 - JUN 30
KLEINMAN, RALPH E.	University of Delaware	MAR 4 - 10
KLIBANOV, MICHAEL	University of North Carolina	MAR 5 - 17
KNOBEL, ROGER A.	U of Texas-Pan American	MAR 5 - 17
KOHLER, WERNER E.	VPI & SU	MAR 5 - 17
KRESS, RAINER	University of Gottingen, Germany	MAR 5 - 17
KURYLEV, YAROSLAV V.	Russian Academy of Sciences	MAR 1 - 31
LANGENBERG, KARL	Universitat Kassel	MAR 5 - 18
LASIECKA, IRENA	University of Virginia	MAR 5 - 17
LAVRENT'EV, MIKHAIL M.	Siberian Branch Russian Academy of Sci.	MAR 5 - 22
LAVRENT'EV, MRS.	Institute of Mathematics	MAR 5 - 22
LEE, C.J.	RPI	MAR 5 - 17
LEVIN, STEWART	Stanford University	MAR 4 - 10
LEVINE, HOWARD	Iowa State University	FEB 7 - APR 7
LEVITAN, BORIS M.	University of Minnesota	MAR 5 - 17
LITTMAN, WALTER	University of Minnesota	SEP 1 - JUN 30
LOECHELT, GARY	Arizona State University	MAR 13 - 17
LOWE, BRUCE D.	Texas A&M University	MAR 5 - 17
LUCAS, RICHARD J.	Loyola University	MAR 6 - 17
MARFURT, KURT	AMOCO Research	MAR 5 - 10
MCLAUGHLIN, JOYCE	Rensselaer Polytech. Institute	MAR 5 - 16
MILLER, DOUGLAS	Schlumberger-Doll Research	MAR 5 - 18
MONK, PETER	University of Delaware	MAR 5 - 11
NAGY, JIM	Southern Methodist University	MAR 5 - 17
NAKAMURA, GEN	Science University of Tokyo	MAR 2 - 9
NATTERER, FRANK	Universitat Munster	MAR 12 - 17
NI, WEI-MING	University of Minnesota	SEP 1 - JUN 30

NOLET, GUUST	Princeton University	MAR 12 - 16
NOWACK, ROBERT	Purdue University	MAR 5 - 17
PANIZZI, STEFANO	Universita di Parma	FEB 5 - JUN 30
PAPANICOLAOU, GEORGE	Stanford University	MAR 5 - 17
PAPANICOLAOU, VASSILIS	Wichita State University	MAR 11 - 18
PATRICK, SHERYL	University of Notre Dame	MAR 5 - 12
PELINOVSKY, DMITRY	Russian Academy of Sciences	MAR 5 - 17
PEREYRA, VICTOR L.	Weidlinger Associates	MAR 5 - 17
PERRY, PETER A.	University of Kentucky	JAN 15 - MAR 30
PIJPERS, F.P.	Uppsala Astronomical Observatory	MAR 5 - 17
PILANT, MICHAEL S.	Texas A&M University	MAR 5 - 18
PODVIN, PASCAL	Ecole des Mines de Paris	MAR 1 - 31
POLING, T. CRAIG	UNISYS	MAR 5 - 17
POTTHAST, ROLAND	University of Gottingen	MAR 5 - 17
POWELL, JEFFREY O.	Iowa State University	MAR 5 - 17
PRESTINI, ELENA	Universita di Roma	MAR 1 - APR 12
RAKESH	University of Delaware	JAN 2 - MAR 31
RAMM, ALEXANDER G.	Kansas State University	MAR 5 - 17
REJTO, PETER	University of Minnesota	SEP 1 - JUN 30
RESNICK, JEFFREY	Acuson	MAR 13 - 17
RITMAN, ERIK	Mayo Clinic	MAR 5 - 17
ROBERTS, THOMAS	Armstrong Lab, Brooks AFB	MAR 5 - 17
ROSALES, ROLDOLFO	MIT	MAR 20 - APR 20
RUNDELL, WILLIAM	Texas A&M University	MAR 5 - 15
SACKS, PAUL	Iowa State University	JAN 2 - MAR 31
SATTINGER, DAVID	University of Minnesota	SEP 1 - JUN 30
SCHERZER, OTMAR	Kepler-Universitaet Linz	MAR 5 - 18
SEI, ALAIN	Rice University	MAR 5 - 17
SEN, MRINAL	University of Texas, Austin	MAR 5 - 17
SHAW, FRANK	U. of California-Riverside	JAN 1 - AUG 31
SMITH, K.T.	Oregon State University	MAR 11 - 18
SOHN, WONKYU	Seoul National University	JAN 1 - MAR 31
SOLMON, DON	Oregon State University	MAR 11 - 16
SOMASUNDARUM, MANJULA	RPI	MAR 5 - 17
SOMERSALO, ERKKI	Helsinki, Finland	MAR 10 - 18
SONG, HUA	University of North Carolina	MAR 6 - 17
SPIVACK, MARK	University of Cambridge	MAR 1 - 23
STARK, PHILIP	U. of California-Berkeley	MAR 5 - 17
STEPANYANTS, YURY A.	Russian Academy of Science	MAR 5 - 17
STORK, CHRISTOF	Advance Geophysical Corporation	MAR 5 - 17
STRAUSS, WALTER	University of Houston	MAR 5 - 17
SUN, ZHIMING	Iowa State University	MAR 1 - 30
SUN, ZIQI	Wichita State University	MAR 1 - 31
SVERAK, VLADIMIR	University of Minnesota	SEP 1 - JUN 30
SYLVESTER, JOHN	University of Washington	MAR 14 - 17
SYMES, WILLIAM	Rice University	MAR 1 - 17
TAYLOR, MICHAEL	University of North Carolina	MAR 6 - 17
TOLMASKY, CARLOS FABIAN	University of Washington	MAR 12 - 18
UHLMANN, GUNTHER A.	University of Washington	MAR 5 - 17
VERSTEEG, ROELOF	University of Connecticut	MAR 5 - 17
VOGELIUS, MICHAEL	Rutgers University	MAR 11 - 17
WALL, DAVID J. N.	University of Canterbury	MAR 5 - 17
WEGLEIN, ARTHUR	Schlumberger-Cambridge Research	MAR 5 - 17
WHITE, BENJAMIN S.	Exxon	MAR 5 - 17
WITTEN, ALLEN	University of Oklahoma	MAR 12 - 19
XU, YONGZHI	Georgetown University	MAR 5 - 17

YAGLE, ANDREW	University of Michigan	MAR 5 - 17
YAKHNO, VALERY	Siberian Division, Russian Acad. Sci.	MAR 5 - 18
ZEROUG, SMAINE	Schlumberger-Doll Research Center	MAR 5 - 17
ZIRILLI, FRANCESCO	Universita di Roma "La Sapienza"	SEP 1 - JUN 30

INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

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IMA NEWSLETTER # 226, REVISED

April 1–30, 1995

1994-95 Program
WAVES AND SCATTERING

See the Fall 1994 IMA Update for a full description of the 1994–95 program on Waves and Scattering

News and Notes

IMA Tutorial:

Singularities and Oscillations

April 4–6, 1995
Speakers: Claude Bardos, Michael Beals, Michael Taylor

IMA Workshop:

Singularities and Oscillations

April 10–14, 1995
Organizers: Joseph Keller, Jeffrey Rauch, Michael Taylor

Weekly IMA seminar list now available by list server

The IMA is happy to announce its new e-mail mailing list service. Currently we offer the mailing list "weekly" which is a distribution each Thursday of the next week's schedule of IMA seminars and events.

If you wish to subscribe, simply send an e-mail message to `imalists@ima.umn.edu` whose first line is of the form

`subscribe weekly`

If your preferred e-mail address is different from the one from which you are sending the request, the first line should be

`subscribe weekly you@e.mail.address`

The subject line and the rest of the message are ignored. Questions or problems should be sent to `owner-weekly@ima.umn.edu`.

The current weekly schedule is also available on request via `finger seminar@ima.umn.edu`. An updated `.dvi` file of the IMA Newsletter (current and recent) is also available ananymously via `ftp ftp.ima.umn.edu` or through the world-wide web `http://www.ima.umn.edu`.

Schedule for April 1–30, 1995

Monday, April 3

SEMINAR IN { **Mathematical Physics** / **VinH 570** }

3:30 pm	**Mikhail Foursov** Univ. of Minnesota	The nonclassical conditional symmetries invariant and partially invariant under the classical Lie symmetries

Abstract: In this talk a new way of finding the nonclassical conditional symmetries of a PDE is explained. It was proved by E. Vorob'ev that the determining equations for nonclassical conditional symmetries inherit the classical symmetry group of the original equation. The other main idea behind the described method is the notion of invariant and partially invariant solutions to a partial differential equation (system of PDEs) under a classical symmetry group.

The method is illustrated on the example of the equation $u_{tt} = u\,u_{xx}$. This method is very useful in this case, since the system of determining equations for nonclassical conditional symmetries cannot be solved in any sort of generality. As a result, more than fifty invariant symmetries and fourteen partially invariant symmetries are obtained.

Organizer: Peter Olver

IMA Tutorial:

Singularities and Oscillations

April 4–6, 1995

Speakers: Claude Bardos, Michael Beals, Michael Taylor

Tuesday, April 4

Talks today are in the Seminar Room, Vincent Hall 570

9:00 am	**Registration and Coffee**	VinH 514 and IMA Lounge, VinH 502
9:30 am	**Welcome and Orientation**	A. Friedman, R. Gulliver
9:45 am	**Claude Bardos** University of Paris, VII	High-frequency analysis for the wave equation, I

Abstract: These lectures are concerned with the analysis of the linear wave equation. I intend to present the different tools now available and show that there is a close connection between the type of tool to be used and the results that are in view.

A detailed program would be as follows:

(1) Global and local energy method for finite speed of propagation.

(2) Relation between rays and bicharacteristics.

(3) Gaussian beams, explicit and asymptotic. Local decay of energy approximation of some of the eigenvalues of the Laplacian.

(4) Wave front set and defect measure.

(5) Application to observation and control.

(6) Propagation of analytic singularities connection with sharp asymptotics and Holmgren uniqueness theorem.

10:45 am	**Coffee Break** IMA Lounge, Vincent Hall 502	
11:15 am	**Michael Taylor** University of North Carolina	Microlocal Analysis and Nonlinear PDE, I

Abstract: We will survey applications of microlocal analysis to problems in nonlinear PDE. We will particularly describe the "paradifferential operator calculus" of J. Bony and Y. Meyer. In addition to applications to wave propagation, studied in Bony's first paper, there are connections with a rather broad spectrum of nonlinear problems, ranging from Schauder estimates for solutions to nonlinear elliptic PDE (and refinements, which might be called "smooth tame" estimates), to results in the area of "compensated compactness," to the sufficiency of Zygmund space estimates for the persistence of solutions to nonlinear evolution equations, to list a few examples.

2:00 pm	**Michael Beals** Rutgers University	Microlocal Analysis, Linear and Nonlinear

Abstract: The basic techniques of localization in phase space are discussed. The geometric definition of the wave front set of a distribution is recalled, in order to analyze regularity of solutions to general PDEs. The classical interpretation for solutions to hyperbolic equations — the relationship between rays and waves — is emphasized. Pseudodifferential operators, the tools for carrying out microlocal analysis, are treated in the context of the function spaces on which they are bounded. The simplest nonlinear estimates and results on the interpolation of operators are given.

4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

SEMINAR IN { **Combinatorics**
Vincent Hall 570

4:40 pm	**Anatol N. Kirillov** Steklov Math. Institute	Combinatorics of Kostka polynomials

Victor Reiner, Organizer

Wednesday, April 5

9:45 am	**Claude Bardos** University of Paris, VII	High-frequency analysis for the wave equation, II
10:45 am	**Coffee Break** IMA Lounge, Vincent Hall 502	

11:15 am	**Michael Taylor** University of North Carolina	Microlocal Analysis and Nonlinear PDE, II
2:00 pm	**Michael Beals** Rutgers University	Regularity measured in Sobolev spaces

Abstract: The classical results on the propagation of singularities and of regularity for solutions to linear and nonlinear wave equations are presented. The presence of purely nonlinear weak singularities and the failure of the weak Huyghens principle is discussed. Refined regularity results, involving lower order singularities than those for which Schauder's lemma can be used, are also given.

Thursday, April 6

9:45 am	**Claude Bardos** University of Paris, VII	High-frequency analysis for the wave equation, III
10:45 am	**Coffee Break** IMA Lounge, Vincent Hall 502	
11:15 am	**Michael Taylor** University of North Carolina	Microlocal Analysis and Nonlinear PDE, III
2:00 pm	**Michael Beals** Rutgers University	Size measured in Lebesgue spaces

Abstract: Local-boundedness estimates for solutions to the classical wave equation in L^p spaces for $p \neq 2$ are presented. Several estimates involving the time decay of solutions when measured in norms other than the energy norm are obtained. These results are applied to give global existence results for solutions to certain semilinear equations.

3:10 pm	**Math department Tea** Math Commons Room, Vincent 120	

Mathematics Colloquium, Room Vincent Hall 16

3:30 pm	**Peter Bates** Brigham Young University	Traveling waves for nonlocal or high-order parabolic equations arising in the theory of phase transitions

Friday, April 7

SEMINAR ON INDUSTRIAL PROBLEMS

11:15 am	**James Cavendish** General Motors Research Labs	The mathematics of surface modeling: impacts of design and manufacturing

Abstract: In industry today, product designers often model complex surfaces such as sheet-metal panels, plastic containers and optical lenses on CAD systems.

These mathematical surfaces then become the starting point for important downstream applications including computer-aided engineering (for example, finite-element structural analysis) and manufacturing (for example, NC

programming). Despite the importance of manufacturing applications, the concerns related primarily to product design have usually driven the specific mathematics and computational approaches used to represent surfaces. Consequently, surfacing mathematics developed for product design has not always produced representations good for manufacturing. The speaker will describe how design and manufacturing issues have together defined the mathematics and computer algorithms used to design and represent multi-featured surfaces at General Motors.

The seminar meets in Vincent Hall 570

IMA Workshop:

Singularities and Oscillations

April 10–14, 1995

Organizers: Joseph Keller, Jeffrey Rauch, Michael Taylor

The topic of this workshop is singular and highly oscillatory solutions of wave equations. These solutions have classically served to reveal the modes of propagation described by an equation. This was the content of the classical theory of geometrical optics. These ideas have been forged into a powerful machine under the name "microlocal analysis" which is one of the centerpieces of the theory of linear partial differential equations.

Over the last decade many of these ideas have been extended to nonlinear problems. The propagation of weak singularities is now quite polished. Strong singularties and high frequency oscillations are topics of active research.

Parallel, and sharing many techniques, is the study of the development and non-development of singularities in initially smooth nonlinear waves. For example, the mechanism for breakdown in nonlinear Schroedinger equations is a topic of active current scientific controversy, and the non-development of singularities for several critical-exponent problems in geometry and mathematical physics is a subject in which great progress has recently been made.

Geometric optics, in the guise of ray methods, is of great utility in describing solutions and is the backbone of many numerical methods for both direct and inverse problems. Here tools of long practical history are receiving detailed and rigorous analysis as for example the geometric theory of diffraction which was formally derived by J.B. Keller in the 50's and rigorously analyzed by Lebeau in the mid 80's.

In this workshop we hope to bring together specialists in the following fields:

1. The microlocal analysis of wave propagation. In particular the geometric theory of diffraction and nonlinear diffraction.
2. The propagation of weak and strong nonlinear singularities.
3. The analysis of blowup, that is, the development of singularities and non-blowup or global solvability.
4. The propagation and interaction of high-frequency nonlinear waves.
5. The use of geometric or ray methods in devising and analyzing computational methods.

Monday, April 10

Talks today are in the Conference Hall, EE/CS 3-180

8:45 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:15 am	**Welcome and Orientation**	Avner Friedman, Robert Gulliver, Jeffrey Rauch
9:30 am	**Jeffrey Rauch** University of Michigan	Waves, Rays, Dispersion, and, Phase Matching

Abstract: The underlying theme in this workshop is wavelike solutions of hyperbolic equations. These solutions have spatially localized structures whose evolution in time can be followed. The most common are singularities and modulated high-frequency (short-wavelength) solutions. Both involve two radically different spatial scales, and for both the evolution often involves rays of one sort or another.

A review of some of the classical asymptotic methods is followed by the discussion of two physical phenomena, the dispersion of light and the suppression of harmonics in lasers. The pecularity of these two problems is that the small parameter, the wavelength, also appears in the equation. This is a feature shared with semiclassical analysis of quantum systems, and one consequence is that the notion of principal symbol, characteristic variety, and rays are modified.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00 am	**Jean-Marc Delort** Université de Paris-Nord	Non-Lipschitz Conormal Singularities for Euler Equations

Abstract: It has been known for a long time that conormal singularities along a smooth characteristic submanifold for a Lipschitz solution to a quasilinear hyperbolic partial differential equation are propagated by the evolution. The aim of this talk is to show that for *incompressible* hyperbolic equations, analytic conormal singularities are propagated for non-Lipchitz solutions as well.

2:00 pm	**John Hunter** Univ. of California, Davis	Singularities and oscillations in a nonlinear variational wave equation

Abstract: The nonlinear wave equation

$$u_{tt} = c^2(u)u_{xx} + c(u)c'(u)u_x^2$$

describes the propagation of orientation waves in a massive director field when viscous effects are neglected. This equation is the simplest representative of a class of variational hyperbolic partial differential equations. We will compare this class of equations with harmonic maps on Minkowski space ("wave maps") and with hyperbolic conservation laws.

We will show that smooth solutions of the one-dimensional wave equation break down in finite time because their derivative blows up. This contrasts with what happens for wave maps which remain smooth in one space dimension. After the derivative blows up, weak solutions appear to form cusps rather that shocks.

We will also discuss the interaction between oscillations in the derivative and the mean-field. An interesting feature of this equation is that for energy-conserving oscillations one obtains a closed system of PDE's for the mean-field.

4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Tuesday, April 11

Talks today are in the Conference Hall, EE/CS 3-180

9:30 am	**David McLaughlin** Courant Institute	To be announced
10:30 am	**Coffee Break** Reception Room EE/CS 3-176	

11:00 am	**Olivier Gues** Université de Rennes I	Viscous boundary layers and high frequency waves

Abstract: This talk concerns small-viscosity perturbations of mixed semilinear (symmetric first order) hyperbolic systems in several dimensions. The problem is to describe the (smooth and local in time) solution u^ε of the Cauchy-Dirichlet problem for the perturbed system, as the viscosity parameter $\varepsilon > 0$ goes to zero. A "boundary layer" forms in the vicinity of the boundary, where the solution u^ε develops a singularity (with respect to ε).

A recent interesting result is that u^ε admits a complete multi-scale asymptotic expansion of WKB type. This asymptotic expansion provides good understanding and highly accurate desciption of the boundary layer. It also exhibits the relevant "fast scales" contained in the solution's high-frequency fluctuations. As a byproduct one gets the convergence of u^ε to the solution u^0 of some mixed hyperbolic system with maximal dissipative boundary conditions, together with optimal estimates on the convergence rate.

An interesting question is the nonlinear interaction between high-frequency oscillating waves and the boundary layer. Actually, in the case where the boundary belongs to a regular foliation by characteristic hypersufaces (for the hyperbolic unperturbed operator) $\{\varphi = const\}$, one can prove and describe the propagation of high-frequency oscillations with phase φ, along the boundary, inside the boundary layer.

2:00 pm	**Claude Bardos** Université de Paris VII	Propagation of singularities for the system of elasticity with standard boundary conditions: application to observation and control

Joint work with F. Tatout and T. Masrour.

Wednesday, April 12

Talks today are in the Conference Hall, EE/CS 3-180

9:30 am	**Serge Alinhac** Université de Paris-Sud	Blowup of classical solutions of nonlinear hyperbolic equations: a survey of recent results

Abstract: Some recent results on blowup of classical solutions to hyperbolic systems or equations are presented. Emphasis is put on the description of the mechanism, which can be given for some semilinear cases or for cases in one space dimension. For higher dimensions, only asymptotic results have been obtained so far.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	

11:00 am	**Nicholas Burq** École Polytechnique	Scattering poles generated by a corner

Abstract: We compute the high frequency scattering poles for the wave equation with Dirichlet boundary condition in the exterior of an obstacle (with corners) containing a trapped trajectory connecting a corner to itself (the model is Ikawa's balls in which we introduce corners). We obtain an asymptotic expansion of (almost) all poles under any logarithmic curve. We show that these poles are located on logarithmic curves.

1:30 pm	**Rodolfo R. Rosales** MIT	Resonant nonlinear acoustic standing waves

The problem of classifying the solutions of the Euler equations of Gas Dynamics without wave breaking and shocks is an old standing one. These solutions should dominate the large-time asymptotic behavior for any initial data, as any shocks present should decay and vanish.

It has been commonly assumed that these solutions could consist only of entropy waves (no acoustical component; pressure and velocity constant). However, using analytical (perturbations and bifurcations) and numerical

methods, we have constructed a large class of smooth and periodic (in space and time) solutions with nontrivial acoustical component. The mechanism that allows these waves to exist is a resonant interaction between the acoustic modes and the background entropy fluctuations. These interactions introduce a dissipative mechanism that stops and balances wave breaking and shock formation.

The acoustical component amplitude of the waves occurs only in a bounded range. At the maximum amplitude the waves develop corners in their profiles, much like Stokes waves in water. Numerically we have found examples with extremely large acoustical components (pressure variations in the range 10-20%), which can be achieved in the presence of very small entropy variations (0.1%). Nonlinear interactions are then very important. A brief description of the theoretical arguments will be presented and numerical examples will be shown.

Joint work with Carlos M. Celentano and Dmitriy Vaynblat.

2:30 pm **Coffee Break**
Reception Room EE/CS 3-176

3:00 pm **Mark Williams**
Univ. of North Carolina
Nonlinear geometric optics for reflecting and glancing oscillations

Abstract: We give a rigorous justification of geometric optics for a class of Kreiss well-posed semilinear boundary problems where both resonant interactions and glancing modes are present. Errors are $o(1)$ in L_2 as the wavelength tends to zero. We emphasize the difficulties that distinguish boundary problems from problems in free space. These include:

(1) the apparent failure of coherence and symmetry hypotheses alone to guarantee existence of the exact solution on a fixed domain independent of the wavelength,

(2) inconsistent transport equations associated to glancing modes,

(3) the need to use eigenvectors associated to nonreal eigenvalues in constructing approximate solutions, and

(4) the appearance of unbounded families of projection operators (associated to eigenvalues of high multiplicity) in the profile equations.

SEMINAR IN { **Partial Differential Equations**
Room VinH 570

4:00 pm **Daniel Tataru**
Northwestern University
Carleman estimates and unique continuation for the semi-linear wave equation

Organizer: Walter Littman

Thursday, April 13

Talks today are in the Conference Hall, EE/CS 3-180

9:30 am **Patrick Gerard**
Université de Paris-Sud
Microlocal analysis of concentration effects in semilinear wave equations

Abstract: Given a sequence of data with bounded energy, we give sharp sufficient conditions on the microlocal measure of the data in order that the solution of the semilinear wave equation with critical exponent with these Cauchy data, shall be described, up to a strongly convergent term, by the solution of the linear wave equation with the same Cauchy data. The proof relies on a microlocal version of P. L. Lions' concentration–compactness lemma.

10:30 am **Coffee Break**
Reception Room EE/CS 3-176

11:00 am	**Thomas Y. Hou** Caltech	Numerical Capturing of High-Frequency Oscillations on Coarse Grids

Abstract: Many problems of fundamental and practical importance have multiscale solutions. Composite materials, porous media, turbulent transport in high-Reynolds-number flows are examples of this type. In general, analytical results are difficult to obtain. Numerical capturing of high-frequency oscillations in the solution becomes necessary. Due to the limited capacity of computers, it is almost impossible to accurately resolve all the small-scale quantities in the solution. The challenging question is: Can we approximate the correct average quantities using only a coarse grid without resolving all the small scales? This question is of great practical interest. For certain class of nonlinear hyperbolic and elliptic systems, this has been shown to be possible by using the sampling technique and oscillatory bases. Here I will give an overview of the state-of-the-art methodology for constructing efficient particle methods, and multi-resolution methods to approximate highly oscillatory solutions in linear and nonlinear PDEs. Numerical difficulties and some open questions in applications will be addressed.

2:00 pm	**Franck Merle** École Normale Superieure	Recent progress on the blow-up problem for Zakharov equations

Abstract: We prove existence of blow-up solutions for equations of the form

$$\begin{aligned} iu_t &= -\Delta u - nu \\ \Box n &= -\Delta |u|^2 \end{aligned}$$

where $u : \mathbb{R}^N \to \mathbb{C}$ and $n : \mathbb{R}^N \to \mathbb{R}$. We then study qualitative properties of the solution at the blow-up time.

6:00 pm	**Workshop Dinner**	Campus Club, fourth floor of Coffman Union

Wine and cheese will be served starting at 5:30 pm. Dinner at 6:00 will be in the Dale Shephard Room of the Campus Club.

Friday, April 14

Talks today are in the Conference Hall, EE/CS 3-180

9:30 am	**Guy Métivier** Université de Rennes I	Nonlinear oscillations and caustics.

Abstract: The principal aim is to describe different nonlinear effects of focusing for high frequency solutions of semilinear hyperbolic equations. Consider in the past an oscillating wave train solution of the form $u^\varepsilon(t,x) \sim \mathcal{U}(t,x,\varphi(t,x)/\varepsilon)$. The phase φ satisfies an eikonal equation and the profile $\mathcal{U}$ a nonlinear transport equation. The question is to analyze effects of caustics, that is effects which occur when the phase becomes singular. Several phenomena can occur:

1. Blowup of the solution, even before reaching the caustics.

2. Absorption of nonlinear oscillations for strongly dissipative equations.

3. Persistence of nonlinear oscillations after the crossing of the caustic set. In this case, a several-phase expansion is needed, as in the linear theory. But, for nonlinear problems, the different waves interact and nonsmooth tranfers of energy from one wave to another can be observed.

The talk will present examples of such behaviors, with more details for the third one.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	

The following talk is joint with the IMA Seminar on Industrial Problems

11:00 am

David Freier
3M Company

Chemical filtration modelling

Abstract: When a chemical solution of uniform and time-independent concentration is introduced at the inlet of a filter, an initially sharp concentration front begins to migrate through the filter due to advection, and simultaneously spread due to diffusion. When the filter is packed with particles that effectively absorb the dissolved solute, the rate of migration of the front may be orders of magnitude smaller than the solvent flow rate. It is then possible to pass large volumes of solution through the filter without appreciable solute exiting the outlet; the solute introduced at the inlet is held within the filter by the absorbing particles. This phenomenon is the fundamental basis of chemical-separation technology, and in turn of many 3M products.

Mathematical models of the filtration process enhance our understanding of the relationship between the filter and absorbent characteristics and the performance of a filter utilized in a specific product application. More importantly from a commercial perspective, they provide the inverse transformation from required performance characteristics to filter and absorbent design. Theoretical characterization of the chemistry of absorption is exceedingly difficult and unreliable; however given empirical absorption characteristics, theoretical characterization of filter performance and its dependence upon these empirical characteristics and filter and absorbent design is relatively straightforward. We have developed a suite of analytic and numerical models to provide both the forward and inverse mappings for this latter theoretical characterization.

Our models apply to the generic system illustrated in Figure 1. The filter consists of a suspension of spherical absorbent particles of volume fraction $1-\varepsilon$, randomly dispersed between $z=0$ and $z=L$. A solution of inlet concentration $c_i(t)$ is passed through the filter at a uniform flow rate v. The primary objective is to determine the outlet concentration $c_o(t)$ and its dependence upon $c_i(t)$, v, ε, L, the radius of the particles, and the (empirically determined) characteristics of the chemistry of absorption.

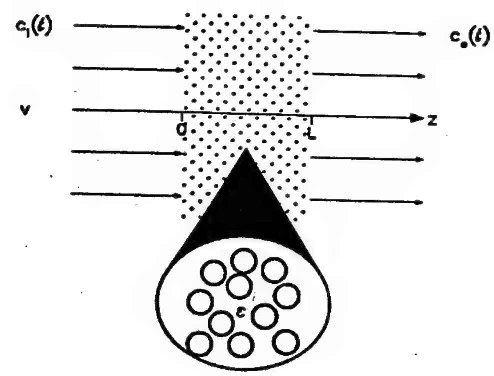

Figure 1: Model System

In general, our models consist of the empirical characterization of the chemistry of absorption, a microscopic description of the occurrence of absorption, and the requirement for conservation of mass. Our most general characterization of the chemistry of absorption is embodied by a non-linear rate equation which accounts for both finite reaction rates (non-equilibrium conditions) and saturation of the absorbent. For many absorbents one of the three special cases listed in Table 1 apply; analytic models are possible for each of these special cases. Our most general description of the occurrence of absorption allows for concurrent absorption and diffusion into the absorbent particles. In the pore model diffusion transports dissolved species to absorption sites in pores permeating the particles. In the solid model absorption occurs exclusively on the exterior surface, followed by diffusion in the solid phase. The dispersed-media model is the small-particle limit of either the pore or solid diffusion model. Enforcement of conservation of mass results in different model equations for different physical scenarios. Four scenarios of particular interest are; batch mode, relevant to liquid-phase laboratory characterization; column mode, relevant to both separations and gas-phase laboratory characterizations; recirculation mode, relevant to "scrubbing" of liquid or gas in closed systems; and arbitrary $c_i(t)$, relevant to scrubbing time-dependent input streams. A single model results from choosing one entry from each column in Table 1. We have completed models for most of the 48 possible combination.

Table 1: Model Components

Chemistry	Occurrence	Conservation
non-linear rate	pore diffusion	batch mode
linear rate	solid diffusion	column mode
irreversible equilibrium	dispersed media	recirculation mode
linear equilibrium		arbitrary input stream

We will present the model equations for one example from the 48 possibilities and describe their solution. For the linear cases the solution procedure demands accurate and efficient inverse Laplace transformation of fairly tortuous kernels/ we will briefly describe a combined analytic/numerical procedure procedure for their evaluation. Selected results will then be preented in order to communicate a physical picture of the filtration process, identify some of the inherent uncertainties, and illustrate the utility of modelling in product design.

2:00 pm	**Michael Taylor** Univ. of North Carolina	Microlocal Phenomena in Nonlinear Evolution Equations

Abstract: The talk will survey a number of examples and results on solutions to various nonlinear evolution equations involving the use of microlocal analysis.

Monday, April 17

Tuesday, April 18

IMA Postdoc Seminar

2:30 pm	**Stefano Panizzi** CNR/Università di Parma	The Cauchy Problem for the Kirchhoff String

Abstract: In his treatise of 1876 G. Kirchhoff proposed the integro-differential equation

$$u_{tt} - \left(T_0 + \frac{E}{2L} \int_0^L u_x^2 \, dx \right) u_{xx} = 0,$$

in order to decribe small transversal vibrations of an elastic string, when the longitudinal motion can be considered negligible with respect to the transversal one.

In this lecture we introduce the model and discuss the various mathematical results on the n-dim generalization of the Kirchhof equation, concentrating on the well-posedness of the Dirichlet-Cauchy problem in bounded domains.

Organizer: Armin Kargol

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

SEMINAR IN { Combinatorics / Vincent Hall 570

4:40 pm	**Dave Bailey** Univ. of Minnesota	Non-broken circuit bases and Weyl group elements

Victor Reiner, Organizer

Wednesday, April 19

Thursday, April 20

Friday, April 21

Monday, April 24

Tuesday, April 25

IMA Postdoc Seminar

2:30 pm	**Nathan Kutz** IMA	Stability of Pulses in Nonlinear Optical Fibers Using Phase-Sensitive Amplifiers

Abstract: This talk considers the stability of soliton-like pulses propagating in nonlinear optical fibers with periodically spaced phase-sensitive amplifiers, a situation where the averaged pulse evolution is governed by a fourth-order nonlinear diffusion equation similar to the Kuramoto-Sivashinsky or Swift-Hohenberg equations. A bifurcation and stability analysis of this averaged equation is carried out, and in the limit of small amplifier spacing, a steady-state pulse solution is shown to be asympotically stable. Furthermore, both a saddle-node bifurcation and a subcritical bifurcation from the zero solution are found. Analytical results are confirmed using the bifurcation software package AUTO. The analysis provides evidence for the existence of stable pulse solutions for a wide range of parameter values, including those corresponding to physically realizable soliton communications systems.

Organizer: Armin Kargol

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

Wednesday, April 26

Thursday, April 27

Friday, April 28

SEMINAR ON INDUSTRIAL PROBLEMS

11:15 am	**Stephen Beissel** Alliant Techsystems	The element-free Galerkin method for the numerical solution of the equations of motion

Abstract: The engineering design process, which involves alternate stages of model construction and analysis, can be carried out more efficiently if the analyses are performed on a numerical model, rathar than an actual prototype. To this point, the finite element method has been the most widely used numerical technique for the analysis of solids, due primarily to its ability to accurately model complex geometries. However, the finite element mesh loses accuracy rapidly when the elements become distorted, as occurs in problems involving large deformations and fracture propagation. A relatively new class of numerical techniques, the element-free Galerkin method, is achieved by expansion of the solution in a basis of moving least-squares functions, as opposed to the piecewise polynomial basis of the finite element method. The result is an element-free mesh of nodes with variable connectivities, allowing for greater flexibility in the configuration of nodes. Several formulation are presented, along with example calculations comparing them to the finite element method.

The seminar meets in Vincent Hall 570

CURRENT IMA PARTICIPANTS

POSTDOCTORAL MEMBERS FOR 1994-95 PROGRAM YEAR

NAME	PREVIOUS/PRESENT INSTITUTION
Bronski, Jared C.	Princeton University
Jaksic, Vojkan	University of Kentucky
Kargol, Armin	VPI&SU
Kim, Dai-Gyoung	Purdue University
Liu, Changmei	University of Rochester
Luo, Erding	UCLA
Patch, Sarah	UC Berkeley
Yu, Shih-Hsien	Stanford University

POSTDOCTORAL MEMBERSHIPS IN INDUSTRIAL MATHEMATICS FOR 1994-95

NAME	PREVIOUS/PRESENT INSTITUTION
Cockburn, Juan C.	University of Minnesota
Copeland, Mark A.	Clemson University
Huntley, Douglas	Northwestern University
Kutz, Jose Nathan	Northwestern University
Nitsche, Monika	University of Colorado

CNRS POSTDOCTORAL MEMBER FOR 1994-95

NAME	PREVIOUS/PRESENT INSTITUTION
Ponenti, Pierre-Jean	Physique Théorique Marseille

VISITORS IN RESIDENCE (as of 3/10)

ACAR, ROBERT	Eastern Montana College	SEP 1 - AUG 31
ALBERT, JOHN P.	University of Oklahoma	APR 4 - 14
ALINHAC, SERGE	Universite de Paris Sud	APR 8 - 30
BARDOS, CLAUDE W.	Universite de Paris VII	APR 1 - MAY 26
BEALS, MICHAEL R.	Rutgers University	APR 3 - 8
BEISSEL, STEPHEN R.	Alliant Techsystems	APR 28 - 28
BURQ, NICHOLAS	Ecole Polytechnique	APR 4 - 14
CAVENDISH, JAMES	General Motors Research and Development	APR 6 - 7
CHENEY, MARGARET	RPI	AUG 15 - JUL 31
DELORT, JEAN-MARC	Laboratoire Analyse, Geometrie et Applic.	APR 9 - 15
FREIER, DAVID	3M	APR 14 - 14
FRIEDMAN, AVNER	IMA	SEP 19 - AUG 31
GERARD, PATRICK	Universite de Paris Sud	APR 9 - 15
GRIKUROV, V.E.	St. Petersburg University	APR 1 - JUN 30
GUES, OLIVIER	Universite de Rennes I	MAR 15 - APR 15
GULLIVER, ROBERT	IMA	SEP 1 - AUG 31
HELFFER, B.	Ecole Normale Superieure	APR 29 - MAY 27
HOLT, LINDA MARIE	California State University	APR 2 - 29
HORN, MARY ANN	University of Minnesota	SEP 1 - AUG 31
HOU, THOMAS Y.	Caltech	APR 8 - 14
KICHENASSAMY, SATYANAD	University of Minnesota	SEP 1 - JUN 30
LAFITTE, OLIVIER	Ctr D'Etudes Limeil Valenton	APR 3 - 19
LEVINE, HOWARD	Iowa State University	FEB 5 - APR 7
LINDBLAD, HANS	Princeton University	APR 9 - 14
LITTMAN, WALTER	University of Minnesota	SEP 1 - JUN 30
MAHADEVAN, L.	Univ. of Illinois-Urbana	APR 10 - 14
MASROUR, TOUFIK	LMSGC LCPC UMR-CNRS	APR 3 - 14
MCLAUGHLIN, DAVID W.	Courant Institute	APR 9 - 14
MELROSE, RICHARD B.	MIT	APR 9 - 14
MERLE, FRANCK	Ecole Normale Superieure	APR 9 - 14
METIVIER, GUY	Universite de Rennes	APR 9 - 14
NI, WEI-MING	University of Minnesota	SEP 1 - JUN 30
PANIZZI, STEFANO	Universita di Parma (CNR)	FEB 5 - JUN 30
RAKESH	University of Delaware	JAN 2 - APR 15
REJTO, PETER	University of Minnesota	SEP 1 - JUN 30
ROSALES, ROLDOLFO	MIT	MAR 20 - APR 15
SACCHETTI, ANDREA	Universita di Modena - CNR	APR 2 - 15
SATTINGER, DAVID	University of Minnesota	SEP 1 - JUN 30
SHAW, FRANK	Univ. of California-Riverside	JAN 1 - AUG 31
SHI, GENBAO	Louisiana State University	APR 1 - JUN 30
SVERAK, VLADIMIR	University of Minnesota	SEP 1 - JUN 30

TAHVILDAR-ZADEH	Princeton University	APR 8 - 14
TATARU, DANIEL	Northwestern University	APR 2 - 15
TATOUT, FREDERIC	ETCA CREA-CNRS	APR 3 - 14
TAYLOR, MICHAEL	University of North Carolina	MAR 6 - JUN 30
VAINBERG, BORIS	University of North Carolina	APR 9 - 16
WEINSTEIN, MICHAEL	University of Michigan	APR 1 - 19
WILLIAMS, MARK	University of North Carolina	APR 9 - 14
ZIRILLI, FRANCESCO	Universita di Roma "La Sapienza"	SEP 1 - JUN 30

INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

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IMA NEWSLETTER # 227, REVISED

May 1–27, 1995

1994-95 Program
WAVES AND SCATTERING

See the Fall 1994 IMA Update for a full description of the 1994–95 program on Waves and Scattering

News and Notes

IMA Tutorial:
Quasiclassical Methods
May 16–18, 1995
Speakers: Bernard Helffer, Thierry Paul

IMA Workshop:
Quasiclassical Methods
May 22–26, 1995
Organizers: Jeffrey Rauch, Barry Simon

Weekly IMA seminar list now available by list server

The IMA is happy to announce its new e-mail mailing list service. Currently we offer the mailing list “weekly” which is a distribution each Thursday of the next week’s schedule of IMA seminars and events.

If you wish to subscribe, simply send an e-mail message to `imalists@ima.umn.edu` whose first line is of the form

`subscribe weekly`

If your preferred e-mail address is different from the one from which you are sending the request, the first line should be

`subscribe weekly you@e.mail.address`

The subject line and the rest of the message are ignored. Questions or problems should be sent to `owner-weekly@ima.umn.edu`.

The current weekly schedule is also available on request via `finger seminar@ima.umn.edu`. An updated `.dvi` file of the IMA Newsletter (current and recent) is also available ananymously via `ftp ftp.ima.umn.edu` or through the world-wide web `http://www.ima.umn.edu`.

Schedule for May 1–27, 1995

Monday, May 1

11:15 am	**Richard Hamilton** Univ. of Calif. San Diego: Vin H 207	Parabolic Problems in Science and Geometry, V

SEMINAR IN { **Real Analysis** / **Vincent Hall 206** }

4:15 pm	**Michael Taylor** Univ. of North Carolina	A wave equation explanation of pointwise Fourier inversion

Tuesday, May 2

10:10 am	**Richard Hamilton** Univ. of Calif. San Diego: Vin H 570	Parabolic Problems in Science and Geometry, VI

IMA Postdoc Seminar

2:30 pm	**Doug Huntley** IMA	Migration of a liquid droplet on a non-uniformly heated surface

Organizer: Armin Kargol

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

SEMINAR IN { **Combinatorics** / **Vincent Hall 570** }

4:40 pm	**Tom Sundquist** Dartmouth College	A Robinson-Schensted algorithm for 3+1 free posets

Victor Reiner, Organizer

Wednesday, May 3

11:15 am	**Richard Hamilton** Univ. of Calif. San Diego: Vin H 207	Parabolic Problems in Science and Geometry, VII

IMA Industrial Postdocs Seminar

The seminar will meet from 1:00 pm - 5:00 pm today. The format of the seminar is:

1. Presentation of projects and problems from industry (Honeywell, Siemens, 3M and Unisys) on which the industrial postdocs are working.
2. Informal suggestions and discussion among the participants.

The seminar is directed by Avner Friedman and Walter Littman. Visitors who plan to attend are requested to inform Dr. Friedman.

The seminar meets in Vincent Hall 570

Thursday, May 4

10:10 am	**Richard Hamilton** Univ. of Calif. San Diego: Vin H 570	Parabolic Problems in Science and Geometry, VIII

Friday, May 5

Monday, May 8

11:15 am	**Richard Hamilton** Univ. of Calif. San Diego: Vin H 207	Parabolic Problems in Science and Geometry, IX

SEMINAR IN { Mathematical Physics, VinH 570

3:30 pm	**Gulmaro Corona-Corona** Univ. of Minnesota	Hamiltonian structures for degenerate AKNS systems

Organizer: Peter Olver

Tuesday, May 9

10:10 am	**Richard Hamilton** Univ. of Calif. San Diego: Vin H 570	Parabolic Problems in Science and Geometry, X

IMA Postdoc Seminar

2:30 pm	**Vojkan Jaksic** IMA	Foundations of dynamical theories of Brownian motion and return to equilibrium in classical mechanics

Organizer: Armin Kargol

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

SEMINAR IN { Combinatorics, Vincent Hall 570

4:40 pm	**Peter Olver** Univ. of Minnesota	Graph theoretic methods in classical invariant theory

Victor Reiner, Organizer

Wednesday, May 10

11:15 am	**Richard Hamilton** Univ. of Calif. San Diego: Vin H 207	Parabolic Problems in Science and Geometry, XI

SEMINAR IN { **Partial Differential Equations**
Vincent Hall 211 }

3:35 pm	**Michael Taylor** Univ. of North Carolina in Vin H 211	Remarks on the Euler and Navier-Stokes equations

Walter Littman, Organizer

Thursday, May 11

10:10 am	**Richard Hamilton** Univ. of Calif. San Diego: Vin H 570	Parabolic Problems in Science and Geometry, XII

Friday, May 12

SEMINAR IN { **Geometric Analysis**
Vincent Hall 213 }

3:35 pm	**Lino Notarantonio** Univ. of Minn.	Relaxed Riemannian Manifolds

Conan Leung, Organizer

Monday, May 15

11:15 am	**Richard Hamilton** Univ. of Calif. San Diego: Vin H 207	Parabolic Problems in Science and Geometry, XIII

SEMINAR IN { **Mathematical Physics**
VinH 570 }

3:30 pm	**Mark Fels** Univ. of Minnesota	Group Reductions and the Variational Bicomplex

Organizer: Peter Olver

IMA Tutorial:

Quasiclassical Methods

May 16–18, 1995

Speakers: Bernard Helffer, Thierry Paul

Tuesday, May 16

Except as noted, talks today are in Lecture Hall EE/CS 3-180

9:00 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:30 am	**Welcome and Orientation**	A. Friedman, R. Gulliver
9:45 am	**Bernard Helffer** École Normale Superieure	h-pseudodifferential operators and applications, I

Abstract: In this minicourse, we shall present the theory of h-pseudodifferential operators with applications to spectral theory: Gutzwiller's formula, Clustering properties, Estimates of Riesz means, *etc.*. Although we shall treat only a regular calculus we shall try through this course to give some preparation to the treatment of the more difficult problems around the Scott conjecture.

10:10 am	**Richard Hamilton** Univ. of Calif. San Diego: Room Vin H 570	Parabolic Problems in Science and Geometry, XIV
10:45 am	**Coffee Break** Reception Room EE/CS 3-176	
11:15 am	**Bernard Helffer** École Normale Superieure	h-pseudodifferential operators and applications, II
2:00 pm	**Thierry Paul** Université Paris–Dauphine	Semi-classical analysis of the Schrödinger equation with an emphasis on coherent states, I

Abstract: We will give in these lectures a review of results concerning the time-dependent and time-independent Schrödinger equation:

$$\begin{aligned} i\hbar\partial_t\psi &= \left(-\hbar^2\Delta + V(x)\right)\psi \\ E\psi &= \left(-\hbar^2\Delta + V(x)\right)\psi \end{aligned}$$

in the limit where the Planck constant $\hbar$ tends to zero (the classical limit).

We will focus on the propagation of the so-called "coherent states"

$$\psi^{\hbar}_{x\xi}(y) = Ce^{-i\frac{x\xi}{\hbar}}e^{i\frac{\xi y}{\hbar}}e^{-\frac{(y-x)^2}{2\hbar}}$$

and show the implications of this kind of result to the spectral measure (trace formula, semi-classical measures, local spectral density, quasi-modes ...). We will in particular discuss several applications to the so-called "scar phenomenon".

The mathematical results will be illustrated by physical examples (both numerical and experimental) of quantum mechanics with chaotic underlying classical dynamics.

The results will be also presented in the situation of the high part of the spectrum of the Laplacian on a compact manifold. Finally the semi-classical limit of perturbation theory (normal forms) will be sketched.

4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

SEMINAR IN $\left\{ \begin{array}{l} \textbf{Combinatorics} \\ \textbf{Vincent Hall 570} \end{array} \right.$

4:40 pm	**Nina Amenta** The Geometry Center	Projections of 4-polytopes: theorems and video

Victor Reiner, Organizer

Wednesday, May 17

Except as noted, talks today are in Lecture Hall EE/CS 3-180

9:45 am	**Bernard Helffer** École Normale Superieure	h-pseudodifferential operators and applications, III
10:45 am	**Coffee Break** Reception Room EE/CS 3-176	
11:15 am	**Thierry Paul** Université Paris–Dauphine	Semi-classical analysis of the Schrödinger equation with an emphasis on coherent states, II
11:15 am	**Richard Hamilton** Univ. of Calif. San Diego: Vin H 207	Parabolic Problems in Science and Geometry, XV
2:00 pm	**Thierry Paul** Université Paris–Dauphine	Semi-classical analysis of the Schrödinger equation with an emphasis on coherent states, III

SEMINAR IN { **Partial Differential Equations**
Vincent Hall 211

3:35 pm	**Margaret Cheney** RPI	Inverse problems for a perturbed dissipative half space

Walter Littman, Organizer

Thursday, May 18

Except as noted, talks today are in Lecture Hall EE/CS 3-180

9:45 am	**Bernard Helffer** École Normale Superieure	h-pseudodifferential operators and applications, IV
10:10 am	**Richard Hamilton** Univ. of Calif. San Diego: Room Vin H 6	Parabolic Problems in Science and Geometry, XVI
10:45 am	**Coffee Break** Reception Room EE/CS 3-176	
2:00 pmm	**Thierry Paul** Université Paris–Dauphine	Semi-classical analysis of the Schrödinger equation with an emphasis on coherent states, IV

Friday, May 19

No talks scheduled.

IMA Workshop:

Quasiclassical Methods

May 22–26, 1995

Organizers: Jeffrey Rauch, Barry Simon

There are a large number of problems where qualitative features of a partial differential equation in an appropriate regime are determined by the behavior of an associated ordinary differential equation. The example which gives the area its name is the limit of quantum mechanical Hamiltonians (Schrödinger operators) as Planck's constant h goes to zero, which is determined by the corresponding classical mechanical system. A second example is linear wave equations with highly oscillatory initial data. The solutions are described by geometric optics whose centerpiece are rays which are solutions of ordinary differential equations analogous to the classical mechanics equations in the example above.

Much recent work has concerned understanding terms beyond the leading term determined by the quasiclassical limit. Two examples of this involve Weyl asymptotics and the large-Z limit of atomic Hamiltonians, both areas of current research.

A classic result of Weyl asserts that the asymptotic number of eigenvalues for the Dirichlet Laplacian of a bounded region in R^n is determined by a volume in a classical phase space. This result has been extended in a variety of directions, including asymptotics of eigenvalue distributions of elliptic operators on compact manifolds. Going beyond leading order in the asymptotics involves surface terms for the classical problem and curvature terms in the manifold case. There are also results for regions with a fractal boundary.

The total binding energy, $E(Z)$, for an atom, with Z electrons and a nucleus of charge Z has been studied in the large-Z limit. In 1973 Lieb and Simon proved that the leading term is given by Thomas-Fermi theory and is proportional to the 7/3 power of Z. Then, Hughes and Siedentop-Weikard found the next (order $Z^{6/3}$) term, and recently Fefferman-Seco have proven a result up to the 5/3 power. This work involves understanding the quasiclassical limit in the presence of singularities in the potential.

An additional area which the workshop will study concerns the effect on the quantum mechanics when the underlying classical mechanics has chaotic dynamics.

Monday, May 22

Except as noted, talks today are in Lecture Hall EE/CS 3-180

8:45 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:15 am	**Welcome and Orientation**	Avner Friedman, Robert Gulliver, Barry Simon
9:30 am	**Rainer Hempel** TU Braunschweig, Germany	Asymptotic distribution of eigenvalues in gaps

Abstract: In solid state physics, the energy spectrum of electrons in a *pure crystal* is described by periodic Schrödinger operators $H = -\Delta + V$, as a first approximation. In many applications, however, one has to deal with semiconductors and insulators with *impurities*. Impurities may create new energy levels inside spectral gaps of H; therefore, they have a direct impact on the conductivity of doped semi-conductors and on the color of crystals (such as ruby and sapphire). In a simple model, we consider the family of operators

$$H - \lambda W, \quad \lambda \in R,$$

where λ is a *coupling constant*, and W a short-range potential modelling the impurity. Here we wish to obtain information on the behavior of the eigenvalues of $H - \lambda W$ inside a gap (a, b) of H. Fixing a control point $E \in (a, b)$, we define the eigenvalue counting function

$$\mathcal{N}(\lambda) = \sum_{0<\mu<\lambda} \dim N(H - \mu W - E), \quad \lambda > 0,$$

where $N(.)$ denotes the kernel of an operator. Depending on the specific properties of W, quasi-classical methods predict the asymptotics of $\mathcal{N}$ more or less correctly (Alama, Deift, Hempel, Birman, Levendorskii, ...). We will report here on some new findings concerning upper bounds for $\mathcal{N}(\lambda)$, as $\lambda \to \infty$, in the case where $W = W_+ - W_-$ is of compact support. These results are somewhat connected with the phenomenon of *trapping and cascading* in 1-dimensional problems, discovered several years ago (Gesztesy, Simon, et al.)

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00 am	**Bernard Helffer** École Normale Superieure	Semiclassical analysis for the ground state energy of a Schroedinger operator with magnetic wells

Abstract: Motivated by a recent paper of Montgomery, we investigate the bottom of the spectrum in the same spirit as the study of the multiple-well problem for the Schroedinger operator.

This is joint work with A. Mohamed (Université de Nantes).

2:00 pm	**S. Jitomirskaya** Univ. of California, Irvine	To be announced

SEMINAR IN $\left\{ \begin{array}{l} \textbf{Mathematical Physics} \\ \textbf{VinH 570} \end{array} \right.$

3:30 pm	**Mark Fels** Univ. of Minnesota Vin H 570	Group Reductions and the Variational Bicomplex

Organizer: Peter Olver

4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Tuesday, May 23

Except as noted, talks today are in Lecture Hall EE/CS 3-180

9:30 am	**Rene Carmona** Univ. of California, Irvine	To be announced
10:30 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00 am	**Michel L. Lapidus** Univ. of California, Riverside	Fractal Drums and Spectral Asymptotics

Abstract: We present mathematical results (of the author and his collaborators) connecting aspects of fractal and spectral geometry. We study the vibrations of "fractal drums"; namely, (i) *"drums with fractal boundary"* (Laplacians on open sets with very irregular boundary) and (ii) *"drums with fractal membrane"* (Laplacians *on* fractals). These problems have significant physical applications to the study of porous media and to that of diffusions or wave propagation on fractals. (See esp. M. V. Berry's work and conjectures.)

(i) We consider the asymptotic distribution of the eigenvalue spectrum, as well as the boundary behavior of the eigenfunctions. We connect various aspects of the question "Can one hear the shape of a fractal drum?" with different notions of fractal geometry (such as the Minkowski fractal dimension of the boundary) and number theory (such as the Riemann zeta-function and the Riemann hypothesis, jointly with C. Pomerance and H.

Maier, respectively). As a prototypical model, we investigate, in particular, the vibrations of the Koch snowflake drum (and its generalizations): (a) from the point of view of the eigenvalue asymptotics (with J. Kigami), (b) from the the point of view of the boundary behavior of the eigenfunctions and their gradient (with M. Pang), (c) by means of computer graphics (with J. W. Neuberger, R. Renka and C. A. Griffith).

In recent joint work with C. He, we also extend many of our results concerning spectral asymptotics and the Weyl-Berry conjecture to "gauge functions" other than the classical power functions.

(ii) We also consider Laplacians *on* fractals (rather than on regions with fractal boundary). We extend (jointly with J. Kigami) Weyl's classical theorem concerning the asymptotic eigenvalue distribution for Laplacians *on* "finitely ramified" self-similar fractals (such as the Sierpinski gasket). Further, we determine explicitly the associated "spectral dimensions". Finally, in recent work of the author, we combine these latter results with techniques from the theory of operator algebras to propose an analogue of the notion of "Riemannian volume" for certain classes of fractals.

2:00 pm	**Volker Bach** T. U. Berlin	Accuracy of Mean Field Approximations to the Ground State Energy of Large Atoms and Molecules

Abstract: In this lecture several mean-field models that yield an approximate description for the quantum mechanics of large atoms and molecules are reviewed: The Hartree-Fock, the Reduced Hartree-Fock model and the Schroedinger operator with Thomas-Fermi potential. The accuracy of the approximative ground state energy these models give compared to the full quantum mechanical model is discussed.

Wednesday, May 24

Except as noted, talks today are in Lecture Hall EE/CS 3-180

9:30 am	**Heinz Siedentop** Universitetet i Oslo	A Proof of the Strong Scott Conjecture

Abstract: The strong Scott conjecture says that the electronic density of a big atom converges—after suitable rescaling—to the hydrogenic density

$$\rho^H(\mathfrak{r}) := 2 \sum_{\nu,\ E_\nu \leq 0} |\psi_n u(\mathfrak{r})|^2$$

where

$$(-\Delta - \frac{1}{|\mathfrak{r}|})\psi_\nu = E_\nu \psi_\nu .$$

This conjecture was recently proven by A. Iantchenko, E. Lieb, and the speaker. Here we will outline the proof and discuss some related results.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00 am	**Andre Voros** Physique Théorique du CEA, Saclay	Exact quantization conditions for 1-d anharmonic oscillators

Abstract: An exact version of the Bohr–Sommerfeld quantization scheme is constructed for any one-dimensional homogeneous anharmonic oscillator (having the potential q^{2M}). The corresponding spectrum emerges as the fixed point of a nonlinear transformation acting upon level sequences within a suitable domain. This mapping itself is explicitly given as a combination of a standard Bohr–Sommerfeld quantization step with a feedback operation from the resulting spectrum. An approximate linear theory suggests, and numerical tests confirm, that our mapping is contractive up to very high (possibly all) degrees of anharmonicity. The exact spectrum is then constructively specified as the attractor of semiclassically correct eigenvalue sequences. (This type of approach ought to extend to general polynomial potentials.)

2:00 pm	**Barry Simon** Cal Tech	Quasiclassical Aspects of some operators with Singular Spectrum

Abstract: I'll discuss the Stolz model (half line Schrödinger operator with potential $cos(sqrt(x))$ and explain a quasiclassical expression for the Lyapunov exponent which is exact. I'll also discuss a model with very high barriers and diffusive, semiclassical spreading of wave packets.

Thursday, May 25

Except as noted, talks today are in Lecture Hall EE/CS 3-180

9:30 am	**A. V. Sobolev** University of Sussex	On the Lieb-Thirring estimates for the Pauli operator

Abstract: The motion of a charged particle with spin in a magnetic field is described by the Pauli operator $H^{(d)}_{Pauli}$, which acts in $L^2(\mathbb{R}^d) \otimes \mathbb{C}^2$ with $d = 2$ or $d = 3$. If one chooses the magnetic vector-potential a in the form $a = (a_1, a_2, 0)$ with $a_k = a_k(x_1, x_2)$ (which is always true for $d = 2$), then the magnetic field B induced by a will be pointed along the x_3–axis, i.e. $B = (0, 0, B)$, $B = \partial_1 a_2 - \partial_2 a_1$. In this case $H^{(d)}_{Pauli}$ looks especially simple:

$$H^{(2)}_{Pauli} = \begin{pmatrix} A_+ & 0 \\ 0 & A_- \end{pmatrix}, \quad A_\pm = (-i\hbar\nabla - a)^2 \mp \hbar B,$$

$$H^{(3)}_{Pauli} = H^{(2)}_{Pauli} + \begin{pmatrix} -\hbar^2\partial_3^2 & 0 \\ 0 & -\hbar^2\partial_3^2 \end{pmatrix}.$$

Here $\hbar \in (0, \hbar_0]$, $\hbar_0 < \infty$, is the Planck constant. The operator $H^{(d)}_{Pauli}$ is non-negative and the point $\lambda = 0$ belongs to its spectrum. If one perturbes $H^{(d)}_{Pauli}$ with the electric potential V decreasing at infinity, then the perturbed operator $H^{(d)}_{Pauli} + V\mathbb{I}$ can have some negative discrete eigenvalues $\lambda_k = \lambda_k(\hbar, a, V)$, $k = 1, 2, \ldots$. We establish for the sums

$$\mathcal{M}_\gamma(\hbar, a, V) = \sum |\lambda_k(\hbar, a, V)|^\gamma, \ \gamma \geq 0,$$

the following Lieb-Thirring type estimate

$$\mathcal{M}_\gamma(\hbar, a, V) \leq C'_{\gamma,d}\hbar^{-d} \int V_-(x)^{\gamma+\frac{d}{2}} dx + C''_{\gamma,d}\hbar^{-d+1} \int b(x_1, x_2) V_-(x)^{\gamma+\frac{d}{2}-1} dx, (*)$$

where $\gamma \geq 1$ for $d = 2$ and $\gamma > 1/2$ for $d = 3$ and the function $b(x_1, x_2)$ is a "smeared" modification of the initial magnetic field B. The field b coincides with B, if the latter obeys some regularity condition, which, in particular, does not allow B to decay at infinity too rapidly. On the contrary, if the decay of B is too fast (for instance, for compactly supported B), the effective field b is considerably different from B.

The proof of (*) involves only elementary methods of the spectral theory for Schrödinger operators: the Birman-Schwinger principle, the diamagnetic inequality and Cwickel type estimates.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00 am	**Thierry Paul** Université Paris–Dauphine	On the pointwise behaviour of semi-classical measures
2:00 pm	**Rüdi Seiler** Technische Universität Berlin	
3:10 pm	**Math department Tea** Math Commons Room, Vincent 120	

Nestor M. Rivière Memorial Lecture, Room Vincent Hall 16

3:30 pm	**James B. Serrin** Univ. of Minnesota	Stability and blow-up for nonlinear wave systems: or, forty years in the wilderness of differential equations
5:45 pm	**Workshop Dinner**	Campus Club, fourth floor of Coffman Union

This dinner is also in celebration of James B. Serrin, on the occasion of his retirement from teaching.

Wine and cheese will be served in the lounge at 5:45; buffet dinner at 6:30 pm in the West wing.

Friday, May 26

Except as noted, talks today are in Lecture Hall EE/CS 3-180

9:30 am	**V. Ya. Ivrii** University of Toronto	Asymptotics of the ground state energy of the molecules in the magnetic field

Abstract: Asymptotics with accurate remainder estimate are derived for molecules in the constant magnetic field as the charge of the nucleus (the number of electrons) Z tends to infinity, the number of nuclei is bounded and the intensity of the magnetic field is $<< Z^3$.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	

The following talk is joint with the IMA Seminar on Industrial Problems

11:00 am	**Gary Strumolo** Ford Motor Company	Aeroacoustic Research in the Automotive Industry

Abstract: As engine noise is reduced, either through better design or increased sound insulation, the noise generated by airflow over the car body becomes increasingly important. Since customer satisfaction is linked to how quiet the passenger compartment is, it is vital that we reduce or eliminate as many noise sources as possible. To accomplish this, we must first understand how these sounds are generated.

After a brief introduction to the concepts and terminology of acoustics, we will illustrate some of the areas of aeroacoustic research currently being investigated in the auto industry. We will then focus on one source of noise – the radio antenna. Simple analytical models will be presented and compared to experimental data. Needed improvements/enhancements to the model will be suggested for future work.

2:00 pm	**I. Sigal** University of Toronto	Ginzburg-Landau Vortices

Abstract: In this talk I will consider the non-stationary Ginzburg-Landau equations. I will present recent mathematical results on their vortex solutions.

CURRENT IMA PARTICIPANTS

POSTDOCTORAL MEMBERS FOR 1994-95 PROGRAM YEAR

NAME	PREVIOUS/PRESENT INSTITUTION
Bronski, Jared C.	Princeton University
Jaksic, Vojkan	University of Kentucky
Kargol, Armin	VPI&SU
Kim, Dai-Gyoung	Purdue University
Liu, Changmei	University of Rochester
Luo, Erding	UCLA
Patch, Sarah	UC Berkeley
Yu, Shih-Hsien	Stanford University

POSTDOCTORAL MEMBERSHIPS IN INDUSTRIAL MATHEMATICS FOR 1994-95

NAME	PREVIOUS/PRESENT INSTITUTION
Cockburn, Juan C.	University of Minnesota
Copeland, Mark A.	Clemson University
Huntley, Douglas	Northwestern University
Kutz, Jose Nathan	Northwestern University
Nitsche, Monika	University of Colorado

CNRS POSTDOCTORAL MEMBER FOR 1994-95

NAME	PREVIOUS/PRESENT INSTITUTION
Ponenti, Pierre-Jean	Physique Théorique Marseille

VISITORS IN RESIDENCE (as of 5/10)

ACAR, ROBERT	Eastern Montana College	SEP 1 - AUG 31
AVRON, J.	The Technion	MAY 21 - JUN 16
BACH, VOLKER	Technische Universitat Berlin	MAY 21 - 28
BANG, JENS	University of Copenhagen	MAY 21 - JUN 16
BARDOS, CLAUDE W.	University of Paris VII	MAY 15 - 26
BEBERNES, JERROLD	University of Colorado at Boulder	MAY 17 - 20
BEMELMANS, JOSEF	Rheinisch-Westf Tech Hochschule	MAY 15 - AUG 15
BERRY, MICHAEL W.	University of Tennessee	MAY 14 - 21
BORTHWICK, DAVID	University of Michigan	MAY 20 - 26
CARMONA, RENE	U of California-Irvine	MAY 21 - 24
CHANG, ROSEMARY	SGI	MAY 17 - 20
CHENEY, MARGARET	RPI	AUG 15 - JUL 31
DRAPER, RICHARD	IDA/Supercomp. Research Center	MAY 17 - 20
DYNIN, ALEXANDER	Ohio State University	MAY 20 - 26
FERNANDEZ, ORLAND0	Universite Paris-Dauphine	MAY 15 - 26
FRIEDMAN, AVNER	Institute for Mathematics	SEP 19 - AUG 31
GESZTESY, F.	University of Missouri	MAY 16 - JUN 17
GRAF, GIAN MICHELE	ETH- Honggerberg	MAY 21 - JUN 17
GRIKUROV, V.E.	St. Petersburg University	APR 1 - JUN 30
GULLIVER, ROBERT	Institute for Mathematics	SEP 1 - AUG 31
HAGEDORN, GEORGE A.	VPI and SU	MAY 20 - 26
HARRELL, EVANS M.	Georgia Institute of Technology	MAY 21 - 28
HELFFER, B.	Ecole Normale Superieure	APR 29 - MAY 27
HEMPEL, RAINER	Technical University of Braunschweig	MAY 20 - 27
HORN, MARY ANN	University of Minnesota	SEP 1 - AUG 31
IANTCHENKO, ALEXEI	University of Oslo	MAY 21 - 26
IVRII, V. YA	University of Toronto	MAY 21 - 26

JITOMIRSKAYA, S.	University of California	MAY 20 - 26
KHUAT-DUY, DAVID	Universite Paris-Dauphine	MAY 15 - 26
KICHENASSAMY, SATYANAD	University of Minnesota	SEP 1 - JUN 30
KLOPP, FREDERIC	John Hopkins University	MAY 16 - 26
LAPIDUS, MICHEL	University of California-Riverside	MAY 20 - 26
LAST, YORAM	California Institute of Technology	MAY 11 - 27
LENHARDT, SUZANNE	University of Tennessee	MAY 17 - 20
LITTMAN, WALTER	University of Minnesota	SEP 1 - JUN 30
LOCKHART, DEBORAH	NSF	MAY 17 - 20
MCDONALD, BERNARD	NSF	MAY 17 - 20
MCDONALD, GARY	General Motors	MAY 19 - 19
NI, WEI-MING	University of Minnesota	SEP 1 - JUN 30
PANIZZI, STEFANO	Universita di Parma (CNR)	FEB 5 - JUN 30
PAPANICOLAOU, GEORGE	Stanford University	MAY 17 - 18
PAUL, THIERRY	Universite Paris-Dauphine	MAY 15 - 26
PRELLBERG, THOMAS	University of Oslo	MAY 15 - 25
REJTO, PETER	University of Minnesota	SEP 1 - JUN 30
ROBERT, DIDIER	Univ. de Nantes	MAY 21 - 27
ROSSI, HUGO	University of Utah	MAY 17 - 20
SATTINGER, DAVID	University of Minnesota	SEP 1 - JUN 30
SEILER, RUEDI	Technische Universitat Berlin	MAY 21 - 26
SHAW, FRANK	U of California-Riverside	JAN 1 - AUG 31
SHI, GENBAO	Louisiana State University	APR 1 - JUN 30
SIEDENTOP, H.	Universitet Oslo	MAY 19 - 26
SIGAL, I.	University of Toronto	MAY 20 - 26
SIMON, BARRY	Caltech	MAY 21 - 26
SOBOLEV, ALEX V.	University of Sussex	MAY 19 - 26
SOBOLEV,V.A.	Samara St. Univ.	MAY 21 - 26
SORENSEN, THOMAS O.	Aarhus Universitet	MAY 14 - JUN 17
STRUMOLO, GARY	Ford Motor Co. Research Engr Center	MAY 25 - 26
SVERAK, VLADIMIR	University of Minnesota	SEP 1 - JUN 30
TATARU, DANIEL	Northwestern University	MAY 15 - 29
TAYLOR, MICHAEL	University of North Carolina	MAR 6 - JUN 30
VAN DEN BERG, M.	Heriot-Watt University	MAY 21 - 26
VOROS, ANDRE	Centre de Physique Theorique	MAY 20 - 27
WEIKARD, R.	University of Alabama at Birmingham	MAY 20 - 25

INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

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Newsletters, Updates and preprints available via
anonymous ftp: ftp.ima.umn.edu, gopher: gopher.ima.umn.edu, www: http://www.ima.umn.edu

IMA NEWSLETTER # 228, REVISED

May 28–June 24, 1995

1994-95 Program
WAVES AND SCATTERING

See the Fall 1994 IMA Update for a full description of the 1994–95 program on Waves and Scattering

News and Notes

IMA Tutorial:

Multiparticle Quantum Scattering with Applications to Nuclear, Atomic and Molecular Physics

June 7–8, 1995
Speakers: Donald J. Kouri, Gian Michele Graf

IMA Workshop:

Multiparticle Quantum Scattering with Applications to Nuclear, Atomic and Molecular Physics

June 12–16, 1995
Organizers: B. Simon, D. Truhlar, W. Hunziker

Weekly IMA seminar list now available by list server

The IMA is happy to announce its new e-mail mailing list service. Currently we offer the mailing list "weekly" which is a distribution each Thursday of the next week's schedule of IMA seminars and events.

If you wish to subscribe, simply send an e-mail message to `imalists@ima.umn.edu` whose first line is of the form

`subscribe weekly`

If your preferred e-mail address is different from the one from which you are sending the request, the first line should be

`subscribe weekly you@e.mail.address`

The subject line and the rest of the message are ignored. Questions or problems should be sent to `owner-weekly@ima.umn.edu`

The current weekly schedule is also available on request via `finger seminar@ima.umn.edu`. An updated `.dvi` file of the IMA Newsletter (current and recent) is also available ananymously via `ftp ftp.ima.umn.edu` or through the world-wide web `http://www.ima.umn.edu`.

Schedule for May 28–June 24, 1995

Monday, May 29

Memorial Day, University holiday. IMA offices will be closed.

Tuesday, May 30

IMA Postdoc Seminar

2:30 pm **To be announced**

Organizer: Armin Kargol

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

SEMINAR IN { Combinatorics, Vincent Hall 570

4:40 pm **John Hoffman**, Secure Computing Corp. — Public Key Cryptography: a general introduction

Abstract: We will describe Public Key Cryptography, describe how it can be used to both digitally sign documents, and transmit documents secretly. This will be followed by a discussion of the RSA public key algorithm, in particular its strengths, weaknesses and why its introduction has spurred such tremendous research in factoring large integers. We will conclude with a discussion of some of the pitfalls in implementing these algorithms, and a demonstration of one of the more popular implementations, PGP. This talk will span both the Tuesday Combinatorics Seminar, and the Friday Probability Seminar. An effort will be made to keep them as independent as possible.

Victor Reiner, Organizer

Wednesday, May 31

Thursday, June 1

Friday, June 2

Monday, June 5

IMA Short Course

11:15 am	**Michael Taylor** Univ. of North Carolina	The Heisenberg group, the harmonic oscillator, and the Weyl calculus, I

Abstract: H.Weyl defined the "Weyl calculus" in an attempt to set up a general quantization procedure. Its formulation is tied to the representation theory of the Heisenberg group (a group which many physicists call the Weyl group).

The Weyl calculus is also useful in microlocal analysis. In this series of two lectures, we will explain how its advantages over other symbol calculi derive from the transparent way in which automorphisms of the Heisenberg group are reflected in the Weyl calculus. We illustrate this with a discussion of the quantum harmonic oscillator

$$H = -\Delta + |x|^2,$$

including Mehler's formula for the semigroup it generates.

Tuesday, June 6

IMA Short Course

11:15 am	**Michael Taylor** Univ. of North Carolina	The Heisenberg group, the harmonic oscillator, and the Weyl calculus, II

IMA Postdoc Seminar

2:30 pm	**Jan Derezinski** Warsaw University	Scattering theory for time-decaying potentials

Organizer: Armin Kargol

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

SEMINAR IN { Mathematical Physics, VinH 570

3:35 pm	**A. Turbiner** UNAM, Mexico	Lie-algebraic discretization of differential equations

Abstract: A certain representation for the Heisenberg algebra in the space of finite-difference operators is established. A procedure of discretization of differential equations possessing an isospectral property is proposed. Using an sl_2-algebra based approach, (quasi)- exactly-solvable finite-difference equations are described. It is shown that the operators having the Hahn, Charlier and Meixner polynomials as the eigenfunctions are reproduced in present approach. Discrete versions of the classical orthogonal polynomials (like Hermite, Laguerre, Legendre and Jacobi ones) are introduced.

Organizer: Peter Olver

SEMINAR IN { Combinatorics, Vincent Hall 570

4:40 pm	**Sergey Fomin** MIT	Total positivity and pseudo-line arrangements

Abstract: Let N be the group of $n \times n$ unipotent upper-triangular matrices. G. Lusztig discovered a close connection between the following two problems:

(i) studying the piecewise-linear maps that relate different labelings of the canonical basis in the quantized enveloping algebra of the Lie algebra of N;

(ii) studying the variety of totally positive elements of N.

Jointly with A. Berenstein and A. Zelevinsky, we obtained:

(i) explicit closed formulas for these piecewise-linear maps;

(ii) formulas for decomposing an upper-triangular matrix into a product of elementary Jacobi matrices, and related total positivity criteria.

The main method is a combinatorial Ansatz based on representing commutation classes of reduced words by pseudoline arrangements.

No background in quantum groups will be required for understanding.

Victor Reiner, Organizer

IMA Tutorial:

Multiparticle Quantum Scattering with Applications to Nuclear, Atomic and Molecular Physics

June 7–8, 1995

Speakers: Donald J. Kouri, Gian Michele Graf

Wednesday, June 7

Except as noted, talks today are in Seminar Room Vincent Hall 570

9:00 am	**Registration and Coffee**	IMA Lounge Vincent Hall 502
9:30 am	**Welcome and Orientation**	A. Friedman, R. Gulliver
9:45 am	**Gian Michele Graf** ETH Zürich	The geometry of N-body systems

Abstract: The standard N-body system consists of N particles moving in space, interacting by two-body forces which vanish in the limit of large separation. Such a system can break apart into separated non-interacting systems of the same type. The different possibilities are labelled by cluster decompositions or, alternatively, by distinguished subspaces of the N-body configuration space. As an application of this geometric viewpoint, we locate the essential spectrum (HVZ Theorem).

10:45 am	**Coffee Break** IMA Lounge Vincent Hall 502	
11:15 am	**Gian Michele Graf** ETH Zürich	The Mourre inequality

Abstract: The Mourre inequality is the key to the spectral analysis of N-body systems. We shall discuss how the thresholds determine the structure of the continuous spectrum. In particular, eigenvalues and thresholds accumulate only at thresholds and are nowhere dense.

2:00 pm	**Donald J. Kouri** University of Houston	Basic Equations of Quantum Scattering

Abstract: We shall derive the Lippmann-Schwinger and time-independent Schrödinger equations from the time-dependent Schrödinger equation and the simplest methods of calculating solutions and scattering information will be presented. Both variational and non-variational approaches will be discussed.

4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Thursday, June 8

Except as noted, talks today are in Seminar Room Vincent Hall 570

9:15 am	**Coffee**	IMA Lounge Vincent Hall 502
9:45 am	**Gian Michele Graf** ETH Zürich	Asymptotic completeness

Abstract: We consider particles interacting through short-range potentials. The long-time behavior is given in terms of independently moving bound clusters, i.e., of composite particles. More precisely, any state is asymptotically equal to a superposition of such states. The proof makes use of the Mourre inequality.

10:45 am	**Coffee Break** IMA Lounge Vincent Hall 502	
11:15 am	**Donald J. Kouri** University of Houston	Wavepacket Treatments of Quantum Scattering

Abstract: Computational treatments of quantum scattering based on wavepackets will be discussed. Polynomial representations of operators will be introduced for the time evolution operator, as well as for the time-independent resolvent operator and spectral density operator. The advantages of these when one desires scattering information for a range of energies will be illustrated.

2:00 pm	**Donald J. Kouri** University of Houston	Optimized Representations of the Hamiltonian for Scattering

Abstract: The distributed approximating functional (DAF) Hamiltonian, and the related "damped DAF Hamiltonian" will be introduced. Computational techniques that scale linearly with the dimensionality of the Hamiltonian matrix will be discussed. Real-time path integral methods of computing the scattering will also be presented.

Friday, June 9

SEMINAR ON INDUSTRIAL PROBLEMS

11:15 am	**Charles Tresser** IBM	Synchronization: from engineering to number theory

The seminar meets in Vincent Hall 570

IMA Workshop:

Multiparticle Quantum Scattering with Applications to Nuclear, Atomic and Molecular Physics

June 12–16, 1995

Organizers: B. Simon, D. Truhlar, W. Hunziker

Multiparticle scattering theory in quantum mechanics is technically complex because of the variety of scattering channels — for example, if one scatters two hydrogen atoms off each other the possibile results include two free protons, two free electrons or a proton and an H-ion. A key issue in the mathematical foundations is that of asymptotic completeness which says that any state of the quantum system is a superposition of bound and scattering states.

Asymptotic completeness for two-body systems with short-range potentials was proven by Kato and Birman in the late 1950's and for three-body problems by Fadeev in the early 1980's. Going beyond three bodies turned out to be remarkably hard. There was important progress by Balslev-Combes, Enss, Mourre, Perry-Sigal-Simon but it was only in 1985 that Sigal and Soffer solved the problem. Their proof is complex but there has been a significantly simplified extension by Graf and Yafeev.

While mathematicians have been focused inwards on these foundational questions, users of quantum-mechanical scattering — notably physicists studying atoms and nucleii and chemists studying molecules — have been developing computational techniques. The theoretical underpinning for these calculations has been the work of Faddeev. One of our goals in this workshop will be to increase communication between the two sides, to allow the computational side to make contact with the new results of Sigal-Soffer-Graf and to stimulate the mathematicians by greater contact with users of the theory.

Monday, June 12

Except as noted, talks today are in Lecture Hall EE/CS 3-180

8:45 am	**Registration and Coffee**	Reception Room EE/CS 3-176
9:15 am	**Welcome and Orientation**	Avner Friedman, Robert Gulliver, Barry Simon
9:30 am	**Donald J. Kouri** University of Houston	Time-Independent Wavepacket Approach to Quantum Scattering Calculations

Abstract: We shall review the derivation of the time-independent Lippmann-Schwinger equation and time-independent Schrödinger equation from the time-dependent Schrödinger equation in order to see the effect of starting the $t = 0$ (initial) wavepacket out a finite distance from the target. It will be shown that there is a more general form of the time-independent Schrödinger equation which possesses an inhomogeneity, this being the $t = 0$ initial wavepacket. For this reason, we refer to the new equation, and its formal solution as the time-independent wavepacket Schrödinger equation (TIWSE) and the time-independent wavepacket Lippmann-Schwinger equation (TIWLSE). The properties of TIWLSE solution of the new equation, including its relation to the standard LS solution of the homogeneous Schrödinger equation, will be explicated. We shall then discuss the computational advantages possible using these new equations. This will include polynomial expansions of the full causal and anticausal Green's operators, as well as other Green's operators satisfying general boundary conditions. We shall also discuss the construction of solutions to the homogeneous Schrödinger equation of the form $\delta(E-H)\chi(0)$, where H is the full system Hamiltonian and $\chi(0)$ is the $t = 0$ initial packet. This will include solutions where $\chi(0)$ is on top of the target. This leads to a particularly robust method for calculating both the bound and scattering states of a system. Finally, we shall discuss a powerful new method for enabling one to do the calculations in a finite box, but without having to introduce "negative imaginary absorbing potentials", so

our Hamiltonian remains Hermitian. This approach allows us to treat the problem completely as a bound state problem but still extract numerically exact scattering information, as well as any true bound states associated with the Hamiltonian. Finally, all of the computational methods to be presented have the feature of scaling *linearly* with the matrix dimensionality (the best possible scaling).

This work is a collaboration between the group at Houston under D. J. Kouri and that at Iowa State under D. K. Hoffman.

10:30 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00 am	**Fritz Gesztesy** Univ. of Missouri	Trace Formulas and Inverse Spectral Problems for Schrödinger Operators

Abstract: A series of recent results on trace formulas for (multi-dimensional) Schrödinger operators will be reviewed. In addition, new results in inverse spectral theory and a general construction of isospectral potentials will be presented in the one-dimensional case.

2:00 pm	**Nimrod Moiseyev** Technion, Haifa	Time-independent scattering theory for general time-dependent Hamiltonians

Abstract: The time-dependent Schrödinger equation with time-dependent Hamiltonian is replaced by another more general differential equation. For the price of increasing the dimensionality of the problem by one, time-independent scattering theory for time-dependent Hamiltonians has been derived. This novel theory enables one to calculate state-to-state transition probabilities when the atomic or molecular systems are exposed even to very high intensity lasers which induce a general time-dependent electromagnetic field. As illustrative numerical examples the breathing excess-photon detachment (EDP) spectrum $C1$ in ArF excimer laser, the harmonic generation in xenon, and the probabilities for different multiphoton dissociation of H_2^+ in high field are given.

4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

A variety of appetizers and beverages will be served.

Tuesday, June 13

Except as noted, talks today are in Lecture Hall EE/CS 3-180

9:00 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Izabella Laba** UCLA	Multiparticle Schrodinger operators with constant magnetic fields
10:30 am	**Transparency session**	One transparency, two minutes each
10:40 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00 am	**Donald G. Truhlar** University of Minnesota	Problems involving nonideal resonances
11:30 am	**Ronald S. Friedman** Indiana/Purdue at Indianapolis	Problems involving nonideal resonances

Abstract: This talk will survey the phenomenology of broad and overlapping resonances in the scattering theory of

molecular collisions. The first aim of the talk will be to show that resonances encountered in molecular collisions are usually not described by the well known isolated narrow resonance formulae. Nevertheless certain regularities are observed. It would be very helpful to have analytic theory available to provide theoretical guidance for interpreting broad and overlapping resonances observed in calculations, and the fact that the observed features show certain systematics that have not been "explained" analytically prompts the belief that mathematical analysis could be very fruitful. Two types of examples will be emphasized: (i) the relationship between the total resonance width and the sum of the partial widths, and (ii) the comparison of trapped-state resonances to barrier resonances, especially from the point of view of the change in background (direct) scattering over the width of the resonance.

In the second half of the talk, we consider quantal scattering by one-dimensional potential energy functions to provide further insight into the nature of barrier resonances, which are also called transition states. In studies of symmetric and unsymmetric potential functions, we show that reaction thresholds associated with barriers are described by poles of the scattering matrix; *i.e.*, chemical reaction thresholds are indeed resonances. As the parameters of the potential function are varied, we follow the 'trajectory' of the poles in the complex energy plane and examine the connection between barrier resonances and conventional resonances associated with wells between barriers. Resonances are further characterized by considering the relationship between the resonance width and the reactive delay time.

2:00 pm	**Alexander Kiselev** California Institute of Technology	Absolutely continuous spectrum for Schrödinger operators with slowly decreasing potentials

Abstract: We prove that for one-dimensional Schrödinger operators with potential $V(x)$ satisfying the decay condition $|V(x)| < Cx^{-3/4-\epsilon}$, the absolutely continuous spectrum fills the whole positive semi-axis. The description of the set in R^+ on which the singular part of the spectral measure may be supported is also given. Extensions on the more general classes of potentials are discussed.

SEMINAR IN $\left\{ \begin{array}{l} \textbf{Combinatorics} \\ \textbf{Vincent Hall 570} \end{array} \right.$

4:40 pm	**Mark Shimozono** MIT	A q-analogue of certain Littlewood-Richardson coefficients

Abstract: Using rigged configurations we define a family of polynomials $P_{\lambda R}(q)$ indexed by a partition λ and a sequence of rectangular partitions R. Remarkably, these polynomials occur as the Poincare polynomials of isotypic components of twisted modules over the coordinate rings of nilpotent conjugacy classes of matrices. The Kostka-Foulkes polynomials are a special case. When $q = 1$ one obtains a Littlewood-Richardson (LR) coefficient. This coefficient counts three kinds of sets: LR tableaux, rigged configurations, and block catabolizable tableaux. The above polynomial is also given by block catabolizable tableaux using the charge statistic. The LR coefficient possesses several symmetries: reordering of the rectangles, transposition of shapes, and contragredient duality. We give bijections on each of the three kinds of sets which realize these symmetries.

This is joint work, partly with Anatol N. Kirillov and partly with Jerzy Weyman

Victor Reiner, Organizer

Wednesday, June 14

Except as noted, talks today are in Lecture Hall EE/CS 3-180

9:00 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**Nils Elander** Stockholm University	Quantization in the continuum: Complex dilated expansions of scattering quantities

Abstract: Physical observables may be derived from the Green function, the Scattering Matrix and the Titchmarsh-Weyl m-function. Such objects possess, at least for Schrödinger-type problems, compact spectral representations

encompasing a set of complex poles. These so called non-redundant poles, are identical to the eigenvalues of the associated Schrödinger equation. The above-mentioned spectral representations allow identification of the individual contributions from these so-called non-redundant poles to observable physical spectral features in terms of their respective residues. A classification of these poles as resonant and background-building ones is suggested. The same poles are also related to the inverse-scattering problems through extensions of the Gel'fand-Levitan and Marchenko equations. Model potential studies indicate that the expansions of the S-matrix, the Green function as well as the associated Titchmarsh-Weyl m-function, converge rapidly, making the method attractive from both conceptional and computational viewpoints. On the other hand, numerical work on the inverse scattering problem has turned out to be less satisfactory. This presentation will include applications of the above method to problems in atomic and molecular physics as well as a discussion of the search for general and accurate numerical methods utilizing, in particular, the exterior complex scaling formulation.

10:30 am **Coffee Break**
Reception Room EE/CS 3-176

11:00 am **Dimitri Yafaev** — New channels of scattering for long-range potentials
Université de Rennes

Abstract: We consider a system of three one-dimensional particles with one of pair potentials $V^\alpha(x^\alpha)$ decaying at infinity as $|x^\alpha|^{-\rho}$, $0 < \rho < 1/2$. It is shown that such a system can possess channels of scattering not included in the usual list of channels called the asymptotic completeness. Similar channels arise in a two-body system with a long-range potential if a tradional condition on its derivatives is relaxed.

2:00 pm **Claude Mahaux** — Theories of atomic and nuclear optical potentials
Université de Liège

Abstract: In atomic as well as in nuclear physics, elastic scattering cross sections can be very accurately reproduced by assuming that the projectile only feels a one-body mean field, called the optical potential. Various microscopic theories of this potential exist, in particular the Green's function approach and the Feshbach projection operator approach. They lead to expressions of the optical potential which are different, for instance which have different analytical properties. These theories will be critically surveyed, with emphasis on existing problems and on criteria which may help identifying the most meaningful approach.

This is joint work with F. Capuzzi (*Annals of Physics* **239**(1995), 57-189.)

Thursday, June 15

Except as noted, talks today are in Lecture Hall EE/CS 3-180

9:00 am **Coffee** — Reception Room EE/CS 3-176

9:30 am **Jens Bang** — The Pauli principle in multiparticle nuclear scattering
Neils Bohr Institute, Copenhagen

Abstract: Different methods of taking the antisymmetry approximately into account in scattering of composite particles and in related bound state problems are reviewed. Their precision and practical applicability is discussed, particularly in relation to light nuclei. One method, based on Courant-Hilbert orthogonalisation, seems very efficient.

10:30 am **Coffee Break**
Reception Room EE/CS 3-176

11:00 am **Percy Deift** — Some asymptotic questions arising in the theory of random matrix models
Courant Institute, NYU

Abstract: Let J be a finite union of intervals on the line. Let $P(x)$ denote the probability that there are no eigenvalues in the scaled union of intervals xJ for a random Hermitean matrix of large order chosen from the Gaussian Unitary Ensemble (GUE), under bulk scaling with mean spacing one. We show how to express $(d/dx)logP(x)$ in terms of the solution of a Riemann-Hilbert problem, and then use a steepest-descent type method to compute the asymptotics of $P(x)$ as x goes to infinity.

2:00 pm	**Shih-I Chu** University of Kansas	Half-Collision Processes of Atoms and Molecules with Intense Laser Fields

Abstract: The nonlinear interaction of atoms and molecules in intense laser fields is a subject of current importance in science and technology. In this talk, several nonperturbative formalisms and computational techniques recently developed for the treatment of novel atomic and molecular multiphoton and nonlinear optical processes in intense and superintense laser fields will be presented.

6:30 pm	**Workshop Dinner** Holiday Inn, Balcony	

Wine and cheese will be served starting at
6:30 pm in the Balcony, which is above the bar near the hotel entrance. Dinner will be served at 7:00 in a room to be announced.

Friday, June 16

Except as noted, talks today are in Lecture Hall EE/CS 3-180

9:00 am	**Coffee**	Reception Room EE/CS 3-176
9:30 am	**To be announced**	
10:30 am	**Coffee Break** Reception Room EE/CS 3-176	
11:00	**Gian Michele Graf** ETH Zürich	Recent progress in multiparticle scattering theory

Abstract: I shall present a review of recent (after 1991) results in the field of multiparticle scattering theory. I will illustrate the underlying geometric constructions.

Monday, June 19

Tuesday, June 20

IMA Postdoc Seminar

2:30 pm	**Monika Nitsche** IMA	On the self-similar behaviour of vortex-ring formation at a circular opening

Organizer: Armin Kargol

NOTE: The Postdoc Seminar is organized by the IMA postdoctoral members, but all interested IMA participants are very welcome to attend. The Seminar meets in Vincent Hall 570.

Wednesday, June 21

Thursday, June 22

Friday, June 23

IMA Industrial Postdocs Seminar

The seminar will meet from 1:00 – 4:00 pm today. The format of the seminar is:

1. Presentation of projects and problems from industry (Honeywell, Siemens, 3M and Unisys) on which the industrial postdocs are working.
2. Informal suggestions and discussion among the participants.

The seminar is directed by Avner Friedman and Walter Littman. Visitors who plan to attend are requested to inform Dr. Friedman.

The seminar meets in Vincent Hall 570

CURRENT IMA PARTICIPANTS

POSTDOCTORAL MEMBERS FOR 1994-95 PROGRAM YEAR

NAME	PREVIOUS/PRESENT INSTITUTION
Bronski, Jared C.	Princeton University
Jaksic, Vojkan	University of Kentucky
Kargol, Armin	VPI&SU
Kim, Dai-Gyoung	Purdue University
Liu, Changmei	University of Rochester
Luo, Erding	UCLA
Patch, Sarah	UC Berkeley
Yu, Shih-Hsien	Stanford University

POSTDOCTORAL MEMBERSHIPS IN INDUSTRIAL MATHEMATICS FOR 1994-95

NAME	PREVIOUS/PRESENT INSTITUTION
Cockburn, Juan C.	University of Minnesota
Copeland, Mark A.	Clemson University
Huntley, Douglas	Northwestern University
Kutz, Jose Nathan	Northwestern University
Nitsche, Monika	University of Colorado

CNRS POSTDOCTORAL MEMBER FOR 1994-95

NAME	PREVIOUS/PRESENT INSTITUTION
Ponenti, Pierre-Jean	Physique Théorique Marseille

VISITORS IN RESIDENCE (as of 5/19)

ACAR, ROBERT	Eastern Montana College	SEP 1 - AUG 31
ADACHI, TADAYOSHI	University of Tokyo	JUN 11 - 16
AVRON, J.	The Technion	MAY 21 - JUN 16
BACH, VOLKER	Technische Universitat Berlin	MAY 21 - 28
BANG, JENS	University of Copenhagen	JUN 11 - 16
BEMELMANS, JOSEF	Rheinisch-Westf. Tech. Hochschule Aachen	MAY 15 - AUG 15
CHENEY, MARGARET	RPI	AUG 15 - JUL 31
CHU, SHIH-I	University of Kansas	JUN 11 - 16

DEIFT, PERCY	New York University	JUN 11 - 18
DEREZINSKI, JAN	Warsaw University	JUN 1 - JUL 8
ELANDER, NILS	University of Stockholm	JUN 11 - 16
ENSS, VOLKER	RWTH–Aachen	JUN 6 - 17
FERNANDEZ, ORLANDO	Universite Paris-Dauphine	MAY 15 - 27
FRIEDMAN, AVNER	Institute for Mathematics	SEP 19 - AUG 31
FRIEDMAN, RONALD S.	Indiana University-Purdue University	JUN 10 - 17
FROESE, RICHARD	University of British Columbia	JUN 11 - 16
GESZTESY, F.	University of Missouri	MAY 16 - JUN 17
GRAF, GIAN MICHELE	ETH- Honggerberg	MAY 21 - JUN 17
GRIKUROV, V.E.	St. Petersburg University	APR 1 - JUN 30
GULLIVER, ROBERT	Institute for Mathematics	SEP 1 - AUG 31
HAGEDORN, GEORGE A.	VPI and SU	JUN 10 - 15
HARRELL, EVANS M.	Georgia Institute of Technology	MAY 21 - 28
HAWKINS, JANE M	University of North Carolina	JUN 1 - 30
HELFFER, BERNARD	Ecole Normale Superieure	APR 29 - MAY 27
HEMPEL, RAINER	Technical University of Braunschweig	MAY 20 - 27
HORN, MARY ANN	University of Minnesota	SEP 1 - AUG 31
JENSEN, A.	Institute for Electronic Systems	JUN 9 - 17
KHUAT-DUY, DAVID	Universite Paris-Dauphine	MAY 15 - 27
KICHENASSAMY, SATYANAD	University of Minnesota	SEP 1 - JUN 30
KISELEV, ALEXANDER	Caltech	JUN 10 - 17
KOURI, DONALD J.	University of Houston	JUN 6 - 16
LABA, IZABELLA	University of California-Los Angeles	JUN 10 - 14
LAST, YORAM	California Institute of Technology	MAY 11 - 27
LEE, TZONG-YOW	Univesity of Maryland	JUN 6 - 17
LITTMAN, WALTER	University of Minnesota	SEP 1 - JUN 30
LOWDIN, PER OLOF	Uppsala University	JUN 11 - 16
MAHAUX, CLAUDE	Universite de Liege	JUN 10 - 17
MOISEYEV, NIMROD	Technion-Israel Institute of Technology	JUN 11 - 16
MOLLER, JACOB SCHACH	University of Aarhus	JUN 6 - 17
NI, WEI-MING	University of Minnesota	SEP 1 - JUN 30
NUMRICH, ROBERT	Cray Research, Inc.	JUN 11 - 16
PANIZZI, STEFANO	Universita di Parma (CNR)	FEB 5 - JUN 30
REJTO, PETER	University of Minnesota	SEP 1 - JUN 30
ROBERT, DIDIER	Univ. de Nantes	MAY 21 - 27
SATTINGER, DAVID	University of Minnesota	SEP 1 - JUN 30
SHAW, FRANK	U of California-Riverside	JAN 1 - AUG 31
SHI, GENBAO	Louisiana State University	APR 1 - JUN 30
SIMON, BARRY	Caltech	JUN 11 - 16
SKIBSTED, E.	Aarhus Universitet	JUN 9 - 16
SORENSEN, THOMAS O.	Aarhus Universitet	MAY 14 - JUN 17
SVERAK, VLADIMIR	University of Minnesota	SEP 1 - JUN 30
TATARU, DANIEL	Northwestern University	MAY 15 - 29
TAYLOR, MICHAEL	University of North Carolina	MAR 6 - JUN 30
TRESSER, CHARLES	IBM	JUN 9 - 9
TRUHLAR, DONALD	University of Minnesota	JUN 11 - 16
VOROS, ANDRE	Centre de Physique Theorique	MAY 20 - 27
YAFAEV, D.	Universite Rennes-1	JUN 11 - 16
YAJIMA, K.	University of Tokyo	JUN 11 - 16